Volume 22 SEPTEMBER, 1938 Number 9

BULLETIN
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American Association *of* Petroleum Geologists

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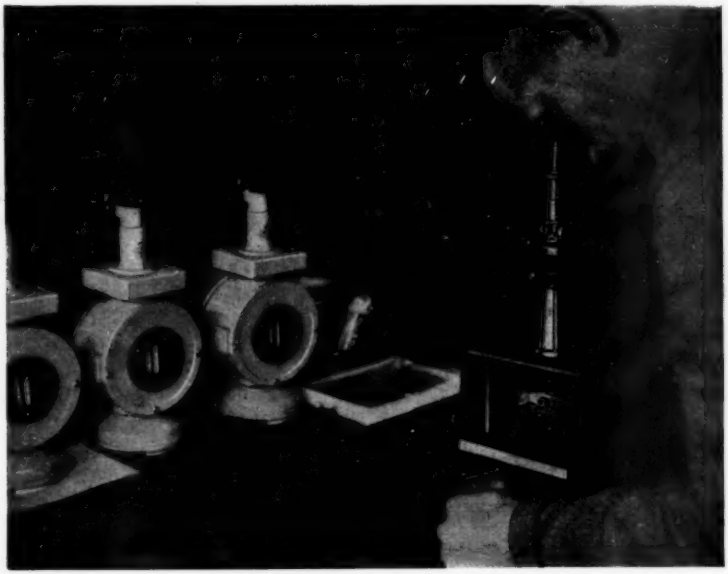

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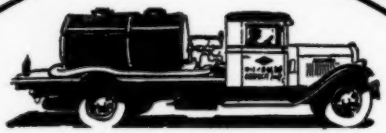

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Volume 22 Number 9

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

SEPTEMBER, 1938

ORIGIN OF McMURRAY OIL SANDS, ALBERTA[1]

J. C. SPROULE[2]
Ottawa, Ontario

ABSTRACT

This paper is not offered as a complete treatise on the origin of the McMurray oil but merely as a further contribution to this interesting study. It appears to the writer that the *in situ* theory, the Clearwater shale theory, the residual theory, and the lateral migration theory are all possible explanations of the genesis of the McMurray bitumen; but they all in some way conflict with facts. However, the theory first proposed by Bell, according to which the petroleum entered the Cretaceous rocks from the underlying Devonian formations, seems to be in close harmony with the evidence at present available. It remains to be seen whether or not Bell's theory will survive the test of future investigation.

INTRODUCTION

Nearly a century and a half has passed since the extensive deposit of oil sand of the McMurray area was first recognized by a white man. It was in 1788 that the intrepid explorer and fur trader, Peter Pond, made known its existence to the outside world. The many noted traders, explorers, and scientists who followed Pond, such as Alexander Mackenzie, David Thompson, Franklin, Richardson, Simpson, and Back, also knew and commented on the occurrence in their records.[3]

They all made use of the oil mixed with balsam to patch their canoes. The genesis of the oil, however, naturally did not concern these men. To them it was little more than an unusual phenomenon of nature, a natural attitude at a time when the science of geology was in its infancy. Oil was, in any case, little used and therefore of but small value until the development of the new petroleum industry in the United States and Canada during the latter half of the past century.

[1] Manuscript received, January 19, 1938.

[2] Geological Survey, Department of Mines and Resources.

[3] R. G. McConnell, "Report on a Portion of the District of Athabaska," *Geol. Survey of Canada Ann. Rept.*, Vol. 5, 1890–91, Pt. D. See Historical Preface.

Beginning about 1875, an economic interest in this isolated deposit developed, stimulated by the increasing market for oil. From that time on, the Federal Department of Mines, and also numerous private companies and individuals, have taken an active part in its exploration. John Macoun of the Geological Survey of Canada referred briefly to these "tar sands" in 1875.[4] Seven years later Robert Bell[5] was commissioned by the same organization to make a special study of the occurrence. Bell was succeeded in the work by R. G. McConnell. Following McConnell, several members of the Geological Survey and Mines Branch of Canada,[6] and the Scientific and Industrial Research Council of Alberta,[7] as well as many private petroleum geologists, have contributed ideas on the occurrence, economic significance, and origin of the oil. Several theories regarding its genesis have been advanced but no one of these has as yet been generally accepted.

It is no exaggeration to say that the problem of the genesis of the McMurray oil sand is one of the most interesting in the field of petroleum geology. That it is the largest known deposit of its kind, and the greatest potential petroleum reserve in North America, make the problem more intriguing.

In the present paper the writer outlines the existing theories of origin and then presents his own view as to the correct explanation of the genesis. The facts on which these theories are founded are contained in the following description of the occurrence and geologic relationships of the McMurray formation. A more thorough knowledge of the physical features of the formation may be gained by reference to the two most complete reports on it: *Mines Branch No. 632*, by S. C. Ells, and *Report 18* of the Scientific and Industrial Research Council of Alberta, by K. A. Clark and S. M. Blair.

GEOGRAPHIC RELATIONSHIPS

The settlement of McMurray is situated in the southern part of the region at the junction of the Clearwater and Athabaska rivers. Waterways is situated on Clearwater River approximately $2\frac{1}{2}$ miles

[4] John Macoun, "Lower Peace and Athabaska Rivers," *Geol. Survey of Canada Rept. of Progress 1875–1876.*

[5] Robert Bell, "Report on Part of the Basin of the Athabaska River, Northwest Territories," *Geol. Survey of Canada Rept. of Progress 1882–1884*, Pt. C.C.

[6] S. C. Ells, "Bituminous Sands of Northern Alberta," *Mines Branch No. 632* (1926). The work done by S. C. Ells, of the Mines Branch, Department of Mines, Ottawa, is of outstanding importance. Ells worked on the economic aspect of the McMurray deposit almost continuously from 1913 to 1931.

[7] K. A. Clark and S. M. Blair, "The Bituminous Sands of Alberta," *Scientific and Industrial Research Council of Alberta Rept. 18* (1927).

from McMurray. It is of interest to note that Waterways is the southern terminus of water transportation on the Athabaska-Mackenzie system and that McMurray is the base for the various air transportation companies. Regular communication with the outside world is maintained by a weekly service over the Waterways branch of the Northern Alberta Railways, which connects Waterways and the city of Edmonton, 300 miles to the south.

Outcrops of the black oil sands are exposed on the banks of the Athabaska for 65 miles below McMurray. For several miles beyond this there are also bedded deposits of reworked oil sands, of glacio-lacustrine origin. Upstream, southwest of McMurray, the oil sands crop out for about 38 miles. The most northerly outcrops have been observed on Reid Creek, 30 miles east of the mouth of Firebag River. They extend for 30 miles eastward up the Clearwater River to Cottonwood Creek. To the south of McMurray drill holes have penetrated the same formation at Kinosis on the Northern Alberta Railway, and near Pelican Rapids on Athabaska River. If the sands are impregnated everywhere within this region it is estimated that the oil sands have an areal extent of more than 8,000 square miles.

GENERAL GEOLOGY

TABLE OF FORMATIONS[8]

Period		*Thickness in Feet*	*Formation*
Quaternary			Gravel, sand, and clay
Cretaceous	Upper	1,100–35	La Biche formation Pelican sandstone
		90	Pelican shale
		280	Grand Rapids formation
	Lower	275	Clearwater formation
		110 to 180+	McMurray formation
	Unconformity		
Devonian		550±	Limestones and shales
	Unconformity		
Silurian		300±	Dolomites, limestones, and shales Salt and gypsum
	Unconformity		
Pre-Cambrian			Quartzites, granites, and granite gneisses

A brief description of the stratigraphic geology of the area is es-

[8] Adapted from table of formations by F. H. McLearn, "Athabaska River Section, Alberta," *Geol. Survey of Canada Summary Rept.* (1916). Additions and corrections made from the writer's field observations and from well logs procured from the Borings Division, Geological Survey, Ottawa.

sential in view of the fact that the oil probably originated in strata at least in physical association with the McMurray formation.

The oldest rocks exposed are pre-Cambrian quartzites, granites, and granite gneisses of the Canadian Shield.[9] The western edge of the shield cuts diagonally across the northeast portion of the area. At its exposed border on Reid Creek the elevation is 1,100 feet above sea-level. In drill holes near McMurray, 70 miles southwest, the pre-Cambrian surface is about 25 feet above sea-level, so that the dip is approximately 15 feet per mile.

Resting on this gentle, though irregular, southwest slope of the shield are the Paleozoic rocks of the region. These comprise Silurian and Upper Devonian[10] limestones and dolomites with minor beds of argillaceous, gypsiferous, and siliceous sediments. The salt, from the Silurian, is the only mineral that has been proved to be of commercial value to the present time.[11] These Paleozoic rocks crop out on the Clearwater River from the Saskatchewan boundary west to McMurray and north on the Athabaska for 30 miles.

Oil stains have been reported on Devonian outcrops throughout the McMurray district. Moreover, oil has also been observed in the Devonian at Vermilion Chutes on the Peace River,[12] at Windy Point and Sulphur Bay on Great Slave Lake, and in other parts of the Mackenzie Basin.[13,14] In the Fort Norman area there are more than 400 feet of Middle Devonian bituminous limestone, overlain by 1,000–1,500 feet of Upper Devonian bituminous shale.[15] At Pelican Rapids and at Athabaska traces of oil are found through several hundred feet below the eroded surface of the limestone.[16,17] The upper part of

[9] S. C. Ells, "Exploration of Bituminous Sand Areas in Northern Alberta," *Mines Branch Investig.* (1931).

[10] P. S. Warren, "The Age of the Devonian Limestone at McMurray, Alberta," *Canadian Field Naturalist*, Vol. 47, No. 8 (1933).

[11] John A. Allan, *Second Annual Report on the Mineral Resources of Alberta* (Alberta Provincial Government, 1920).

[12] S. E. Slipper, "Natural Gas in Alberta," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935).

[13] D. B. Dowling, S. E. Slipper, and F. H. McLearn, "Investigations in the Gas and Oil Fields of Alberta, Saskatchewan, and Manitoba," *Geol. Survey of Canada Mem. 116* (1919).

[14] G. S. Hume, "Oil and Gas in Western Canada" (2d ed.), *Geol. Survey of Canada Econ. Ser. No. 5* (1933).

[15] A. J. Goodman, "Notes on the Petroleum Geology of Western Canada," *Jour. Inst. Petrol. Tech.* (February, 1935).

[16] D. B. Dowling, S. E. Slipper, and F. H. McLearn, *op. cit.*

[17] See also logs of wells of Athadome Oil Company, Borings Division, Geological Survey, Ottawa.

the Paleozoic near Athabaska is particularly rich in oily residue. Of the many wells drilled in northern Alberta that have penetrated the limestone, however, none has obtained oil in commercial quantities. Those drilled near Fort Norman in the Northwest Territories were more successful, production of petroleum being obtained from rocks of Upper Devonian age. It appears that the failure of the Paleozoic in northern Alberta to produce commercial quantities of oil is due to the lack of suitable structures in localities drilled.

With the exception of a fault that crosses Clearwater River near the mouth of High Hills River, there is little evidence of post-Devonian deformation. The present surface of the Paleozoic is, nevertheless, undulatory, due partly to erosion, partly to uneven sedimentation, and no doubt partly to subsequent deformation.

The McMurray formation, of Lower Cretaceous age,[18,19] overlies the Devonian and Silurian unconformably. The attitude of the basal beds is determined by that of the upper surface of the limestones while the upper contact with marine Clearwater shales is conformable or disconformable: conformable in the vicinity of McMurray, and becoming disconformable toward the east. It is interesting to note that the thickness increases from east to west from 90 feet at Whitemud Rapids to nearly 200 feet near McMurray. It thins out toward the southwest near Athabaska Landing to a thickness of 10–30 feet. It is unfortunate that over much of the northeastern part of the area glaciation and other erosive agents have removed the overlying part of the Cretaceous strata and part or all of the McMurray formation.

The most outstanding feature of the McMurray formation is the variation, both vertically and laterally, in the sorting of grains. It is on the whole composed of coarse and fine sands and silts, in places irregularly and highly cross-bedded, but locally it is evenly stratified or massive. The massive beds are more characteristic of the lower strata. A few thin, isolated partings of clay shales and dark carbonaceous shales are found but they are not characteristic. Small allochthonous lignite beds occur in the upper part. Fossil shells have been observed in only one locality but the evidence they provide is sufficient to fix the age of the formation as Lower Cretaceous. More widespread but of little chronologic value are the fossil tree trunks found as a rule more or less horizontal and flattened by static pressure. The wood of this organic débris has, where it occurs in impregnated beds,

[18] F. H. McLearn, "Cretaceous, Lower Smoky River, Alberta," *Geol. Survey of Canada Summary Rept.* (1918), Pt. C.

[19] L. S. Russell, "Mollusca from the McMurray Formation of Northern Alberta," *Trans. Royal Soc. Canada*, Ser. 3, Vol. 26, Sec. 4 (1932).

been so well preserved that the delicate cell structure remains intact even though the freshly mined pieces are as soft as cheese.

The unimpregnated sands themselves are very light in color; in some places, in fact, almost pure white. A microscopic examination reveals that many of the particles have been rounded by frosting and pitting under subaerial conditions. A sedimentary analysis[20] shows that most of the sand grains consist of pure silica. The lesser constituents are, nevertheless, worthy of consideration.

Wherever the McMurray formation is seen in exposures some beds are characterized by many feldspars and large garnets. Kyanite in large, well preserved crystals is extraordinarily common. The presence of hornblende, apatite, staurolite, and other readily destructible minerals, indicates that the source is not far distant. Iron sulphides and oxides, especially pyrite and nodular marcasite, are plentiful and widespread. Iron oxidation products stain and indurate thick beds in many localities.

It appears likely that most of the material constituting this formation has been derived from the pre-Cambrian area on the northeast and east and laid down under conditions of somewhat strong water currents. The nature of the cross-bedding, the imperfect sorting of sand grains, the thinning of the formation, both northeast and southwest from McMurray, and the general structure, support this view.

The degree of impregnation of the McMurray sands is almost as variable a feature as the character of the inorganic constituents. The medium-grained massive and the coarsely cross-bedded strata are generally more highly impregnated, and the more impervious, finely cross-bedded and argillaceous lenticular beds may be low-grade or entirely destitute of oil. Large "islands" of barren sands, some of considerable extent, are not uncommon. Black, highly impregnated beds stand out on exposures in bold relief. Low-grade beds, on the other hand, are dark to light brown, buff or white, and ordinarily weather to more gentle slopes.

"Tar" springs are a conspicuous feature of the richer beds. They issue from strata overlying impervious clay or other partings where the downward progress of exuded oil has been prevented. The springs are apparently due to the saturation of the viscous oil by percolating waters, thereby increasing its volume and its mobility, and facilitating gravity adjustments. On exposure to the atmosphere in pools and on talus slopes, the oil ultimately solidifies.

It is most significant that near Athabaska Landing and on the

[20] Analyses by D. R. Derry, Department of Geology, University of Toronto.

Clearwater River, between Cottonwood Creek and the Saskatchewan boundary, the McMurray sands contain no visible oil. Detailed studies of the barren sands on Clearwater River were made, in order to discover, if possible, the reason for the complete absence of oil in that locality. After a thorough examination of these formations, the conclusion is reached that they contain no significant features without counterparts among the impregnated beds farther west.[21]

In the eastern part of the area the Clearwater formation rests disconformably on the McMurray sands; toward the west, closer to the center of the basin, the contact becomes conformable. The Clearwater series is made up of soft gray and black shales and sandstones with a few concretionary layers. Widely distributed glauconite, ironstone, and selenite bands are numerous. A marine fauna is found throughout.

The Grand Rapids formation overlies the Clearwater shale. Its lower part is concretionary and marine; the upper part is continental and like the McMurray formation contains a few lignite seams. In the Athabaska district C. E. Michener[22] reports an initial estimated daily flow of 20 barrels of heavy oil from the top of the Grand Rapids. Michener says,

> According to the analysis carried out by the Fuel Research Laboratories, Ottawa, the oil found in the Grand Rapids is in every respect similar to that of the McMurray formation farther north.

Grand Rapids rocks are overlain by black, marine, Pelican shale, and this in turn by the younger Cretaceous rocks indicated in the accompanying table of formations.

ORIGIN OF OIL

In view of the potential economic importance of both the oil sands and the beds from which the oil may have been derived, the question of origin is obviously one of great interest, and merits considerably more attention than it has received in the past. Very little systematic research has been done on the problem, with the result that several theories have been brought forward and left incomplete, pending further investigation. No one of them has been widely accepted because of insufficient evidence. In the light of existing knowledge none of these, however, may be discarded as impractical. The principal theories that have been proposed to date are outlined in the following paragraphs.

[21] S. C. Ells, "Exploration of Bituminous Sand Areas in Northern Alberta," *op. cit.*

[22] Oil geologist, Athabaska Oil Company, Toronto. Personal communication.

IN SITU THEORY

The theory of an indigenous origin has been advanced by Arthur Beeby Thompson,[23] London, England, as a result of studies made in the area in 1930. He is of the belief that the oil has been formed *in situ*. The following quotations outline his views.

> Given certain conditions of sedimentation there seems no logical reason why oil should not be formed in sands as well as in clays, shales, or sandy shales. Vegetable remains are fairly abundant in the tar sands, and it may be that other finer macerated organic material of a peculiar type, originally present, has been transformed into petroleum. The character of the sands shows that they were deposited in shallow water subject to strong water currents which could carry organic material, and the method of precipitation and sedimentation may have favoured genetic processes.
>
> Admittedly there is little definite proof that oil has been formed in sands and concentrated *in situ*, but one very striking and pertinent sample is the Derna deposit in Transylvania where in a shallow flat basin of crystalline rocks lie a succession of sedimentary beds of Tertiary age, incorporating lignite seams and bituminous sands much like those of Alberta in character. The sands are richly impregnated with a high-grade bitumen, extractable by solvents or distillation, and there appears no reasonable explanation for the occurrence of the oil except by formation in the beds in which it is found. The lignites are mined and exhibit no signs of oil, nor do the associated clays, and there are no likely source rocks. Subsidiary flexures are practically non-existent, faults show no signs of oil movements, and in the lowest point of the basin the sands are as rich as on the edges.

A further elucidation of the *in situ* theory has been presented by Max W. Ball.[24]

Supporting the *in situ* theory is the interesting fact that the upper part of the Grand Rapids sandstone contains lignite beds and other remains of plant débris, just as does the top of the McMurray formation; and it is from the Grand Rapids formation in the Athabaska district that Michener reports oil of the same kind as that from the McMurray formation.

The presence in the oil sands of well preserved tree trunks and other organic remains seems to favor the idea that the oil was formed during or immediately after the deposition of the sediments and that the delicate structure of the plant débris was preserved by the petroleum. That evidence is not necessarily, however, of a positive nature. R. B. Thomson, head of the Department of Botany, University of Toronto,[25] states that it is not possible to say definitely in what ge-

[23] Personal communication, 1933.

[24] Max W. Ball, "Athabaska Oil Sands: Apparent Example of Local Origin of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 2 (February, 1935).

[25] Oral communication, 1933.

ological age the oil impregnated the plant remains. Thomson cites the case of Pleistocene interglacial conifers from the vicinity of Toronto so well preserved in sands and clays that they can not be distinguished in thin section from recent conifers of the same species.

The sharp decrease in bitumen content east of Cottonwood Creek, in rocks lithologically identical, militates strongly against the *in situ* idea, especially when there is taken into account the abundance of plant remains in the eastern unimpregnated as well as in the western impregnated beds.

CLEARWATER SHALES AS PARENT ROCKS

A theory formulated by F. H. McLearn in 1917[26,27] postulates a derivation of the McMurray petroleum from the overlying Clearwater shales. The Clearwater formation is composed largely of dark marine shales and contains many remains of marine invertebrates. It directly overlies the porous McMurray sands and appears by virtue of its position to be a logical source.

There are nevertheless reasons for believing that the Clearwater formation may not be the source. In the first place, no petroleum residue is now found in either the Clearwater sands or shales. In the second place, the remarkable uniformity in the lithologic character of the Clearwater formation between McMurray and the fourth meridian indicates that the rocks were formed under similar conditions of deposition. The absence of oil from the McMurray sands east of Cottonwood Creek demands, under this theory, that the overlying Clearwater shales here were devoid of organic matter. In view of the similar lithological conditions a change so abrupt is scarcely to be expected.

RESIDUAL THEORY

This theory was suggested by Slipper.[28] Before outlining his theory he makes clear that his is merely an alternative to previous theories, to be proved or disproved by further investigation. Slipper says

My idea may be summed up briefly as follows:

First, the sands and clays of the McMurray formation are residual deposits, formed from the westward erosion of the Palaeozoic limestone during the time interval between the emergence of the Palaeozoic rocks and the Lower Cretaceous.

[26] F. H. McLearn, "Cretaceous, Lower Smoky River, Alberta," *Geol. Survey of Canada Sum. Rept.* (1918), Pt. C.

[27] *Idem*, "Peace River Section, Alberta," *ibid.* (1917), Pt. C.

[28] S. E. Slipper, petroleum geologist, Calgary, Alberta. Personal communication. Also see "Natural Gas in Alberta," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935).

Second, this westward erosion of the Palaeozoic took place as a wearing away of a series of receding escarpments.

Third, the Palaeozoic limestones and dolomites contained horizons impregnated with bitumen and during the recession of the escarpment this bitumen was retained in the residual sands in the manner indicated on the accompanying diagram.

Fourth, subsequent submergence covered the McMurray sands with marine Clearwater shales and the overlying members of the Cretaceous group.[29]

The widespread occurrence of oil in Devonian rocks in northern Alberta and the MacKenzie Basin favors Slipper's theory. So also does the presence of coarse sands in the Paleozoic. Stronger still is the evidence afforded by the actual existence of the "tar sands" of his diagram.

On the other hand studies of the lithology and structure of the McMurray formation, already referred to, do not suggest that it is a residual deposit, but rather that it is of deltaic origin laid down under conditions of strong water currents. Again, the barren nature of the formation east of Cottonwood Creek, notwithstanding the lithological uniformity, militates against the idea. Still another obstacle is the complete absence of oil from the McMurray formation of Athabaska Landing. Here, the barren sands directly overlie bituminous dolomites.

LATERAL MIGRATION THEORY

G. S. Hume[30] believes that the hydrocarbons have entered the McMurray formation from the south and southwest, having been formed in the marine equivalents of the McMurray formation. Hume's views are presented in the following quotation.

In the Wainwright and Ribstone areas, 275 miles southeast of the McMurray area, petroleum has been found in Lower Cretaceous strata which here consist of alternating sandstones and shales together with thin coal seams. No definite marine shales have been recognized. The same is true of the Lower Cretaceous in the Viking area 250 miles south of McMurray and in areas farther to the west. If no marine beds occur in these areas, then the marine formations represented by the Pelican shale, the lower part of the Grand Rapids, and the Clearwater formation, must thin out and disappear in the area south and west of McMurray where the shorelines of these former seas must occur. These shorelines with lagoons and bays of black shale deposition would be very favourable places for the formation of petroleum and it is, therefore, highly probable that the bitumen now found in the McMurray formation is the residue of oil that migrated from its place of origin in the south and southwest. The dip of the formations to the south and southwest from McMurray is quite in accord with this theory of migration, as is also

[29] See Figure 1 for Slipper's diagram.

[30] S. C. Ells, *op. cit.* (reference 9).

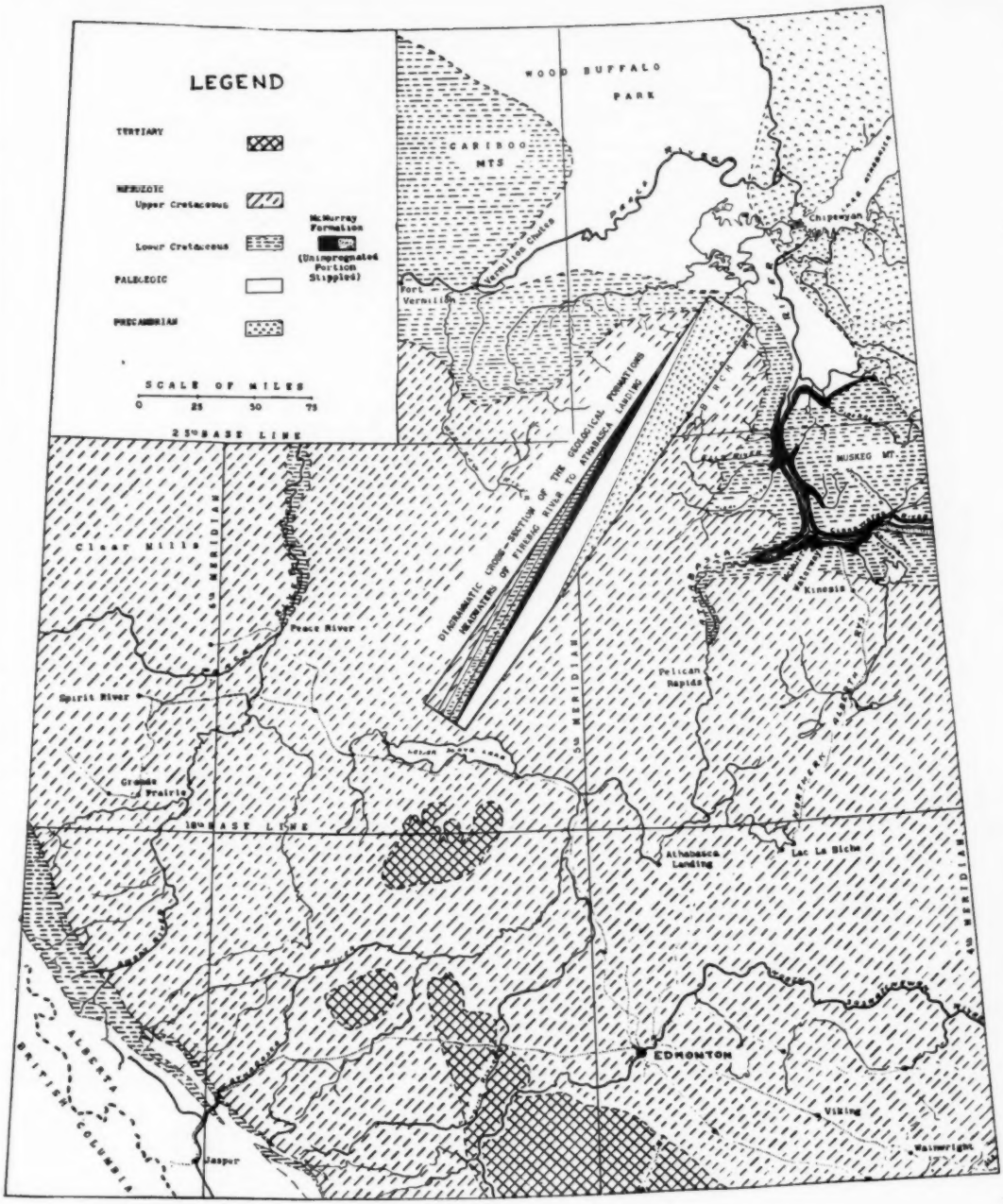

FIG. 1.—Map of part of northern Alberta showing areal distribution of McMurray formation.

the fact that the richer and more homogeneous deposits of bituminous sand occur in the western and southwestern part of the area as described by S. C. Ells. The origin of the petroleum in strata of Lower Cretaceous age is quite in contrast to former beliefs that it originated in the underlying Devonian limestones. A number of wells have penetrated the whole of the Palaeozoic section in the McMurray area and have shown no strata which are probable source beds for oil.

Some of the facts which do not appear to be in keeping with this theory are as follows.

First, there is no visible oil residue cropping out in the marine Clearwater formation on the Clearwater and Athabaska rivers or in the Loon River formation where it crops out on the Loon and Red rivers and at Vermilion Chutes, and it is from lateral equivalents of these that according to this theory the oil has been derived. Any oil originating in these formations should be found in them if it is found anywhere. Both these formations contain porous horizons that should harbor oil as readily as the McMurray formation. The migrating shorelines of the Loon River-Clearwater sea with their "lagoons and bays of black shale deposition" passed over the McMurray formation twice; it does not appear likely that it was only in the region southwest of McMurray that the life along the shorelines was such as to produce oil. We can not in fact be sure that the Lower Cretaceous in Alberta has produced any of the oil that is found there.

Second, petroleum would have to be sufficiently mobile to migrate laterally long distances with little or no change in gravity. The large amount of primary sulphides and sulphates noted in the mineral analyses of McMurray sands should result in difficulties through producing the polymerization of migrating oil, causing the formation of a bitumen-like substance, thereby hindering its progress. Researches have shown that the high viscosity of the McMurray hydrocarbons is in fact due to high sulphur content rather than to loss of volatiles.[31] It is actually a virgin oil; certainly not a "residue" in the ordinary sense of the word.

The highly lenticular nature of the beds of the McMurray formation and the many partings of shale and fine sand should present a further obstacle to a theory that demands lateral migration for any great distance, particularly in a series that has not been subjected to much metamorphism.[32]

Third, the oil, migrating northward, has not gone nearly as far

[31] Max W. Ball, *op. cit.*

[32] E. M. Parks, "Migration of Oil and Water, a Further Discussion," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 6 (1924).

east up the Clearwater River as it ought to have done in keeping with this theory. According to the theory the oil at Reid Creek has penetrated about 50 miles farther from the source than that on the Clearwater River, and that has taken place along beds of similar lithologic character. Under the circumstances it would be more natural to conclude that the source of the oil lies northwest of McMurray.

The fourth opposing factor dovetails with this latter supposition, regarding the location of the source. Oil from the south of the area (Pelican Rapids and McMurray) is of the same chemical composition as that which crops out in the north (near the mouth of Firebag River). On Ells River, however, northwest of McMurray, it is lower in sulphur and correspondingly high in the lower boiling petroleum constituents,[33] further evidence that the source of the oil is more probably northwest than south or southwest of McMurray.

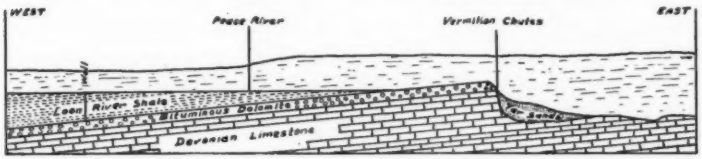

FIG. 2.—Diagrammatic cross section of Vermilion Chutes, Peace River, Alberta. Length of section about 15 miles. *Tracing from S. E. Slipper's original.*

It is true, as Hume points out, that several wells have penetrated Paleozoic rocks in the immediate vicinity of McMurray without encountering favorable source beds for the oil. It should be remembered, however, that a large part of the Paleozoic section of that part of Alberta is not present in the area drilled.[34] The sequence actually becomes more complete toward the west where successively younger beds dipping westward rise to the plane of unconformity between Paleozoic and Cretaceous rocks.

A theory advanced by L. G. Huntley in 1915, and closely allied with that proposed by Hume, has been discussed in a previous issue of this *Bulletin* by Ball.[35]

ORIGIN IN UNDERLYING PALEOZOIC STRATA

Robert Bell was the first to suggest the Paleozoic formations as possible source rocks.[36] Bell considered that the oil seeped upward

[33] K. A. Clarke and S. M. Blair, *op. cit.*

[34] See accompanying diagram and map.

[35] Max W. Ball, *op. cit.*

[36] Robert Bell, *op. cit.*

along cracks in the Paleozoic into the overlying porous McMurray sands.

The writer of this article spent the field season of 1931 studying the problem of the origin of the McMurray oil, under the supervision of S. C. Ells of the Mines Branch, Ottawa. During the field season the various theories of origin were tested in the light of the evidence at hand. The final conclusions arrived at were to a great extent influenced by Ells' helpful suggestions, and his wealth of information regarding the details of the occurrence. Thanks are also due to C. S. Evans, Union Gas Company, Chatham, Ontario, and G. S. Hume, of the Geological Survey, and to Max W. Ball, consulting geologist, Denver, Colorado, whose criticisms and suggestions are much appreciated.

The evidence at hand favors Robert Bell's theory more than any of the others. It is suggested here, as a further elucidation of Bell's theory, that the petroleum entered the McMurray formation from the underlying Paleozoic at some point or points between the Athabaska and Peace rivers; midway, perhaps, between McMurray and Fort Vermilion. This may have come about as a result of either one or the other of two sets of conditions.

It is a reasonable supposition that a body of oil collected in Paleozoic rocks, on the south side of the saddle between the "Alberta basin" and the "MacKenzie basin." Or it may have collected on some more local structure such as the northward extension of the Athabaska fold.[37] During the Laramide revolution crevices formed in the Paleozoic in this region, through which restricted ports of entry the petroleum invaded the McMurray formation and spread outward to the present boundaries of the impregnated body. Working on the same supposition we may assume that some faults occurring in Cretaceous rocks permitted the migration of minor quantities of petroleum to higher levels, which would explain the presence of oil in the Grand Rapids sandstone.

The attitude of the Devonian rocks to the overlying McMurray formation brings another possibility within the realm of probability. As a result of the truncation of these inclined beds successively younger Paleozoic strata are exposed as we pass from the Shield in a westerly direction toward the axis of the "Alberta syncline." The massive dolomites and thinly banded arenaceous and argillaceous limestone at Cascade Rapids, in Sec. 8, T. 89, R. 2, and eastward, are Silurian. The limestones and shales in the vicinity of McMurray are

[37] F. H. McLearn, "Athabaska River Section, Alberta," *op. cit.*

Upper Devonian (Portage-Naples) in age.[38] The upper limestones at Lesser Slave Lake are generally regarded as Devonian but there is a possibility that they are Carboniferous. The fact that exposures of Devonian rocks are not oily where they crop out at McMurray and on the Athabaska River north of McMurray does not signify much one way or the other. North of McMurray the Athabaska River follows along the strike of the Paleozoic so that not more than 300 feet, at the most, of the Devonian is exposed, and 300 feet is but a small part of the Devonian. It has been proved by well drilling that the Paleozoic toward the central and western part of the trough is petroliferous; sufficiently petroliferous to have provided the McMurray sands with their oil, given the proper structural conditions. It is true that the dips in the Paleozoic strata are low,[39] but even so it seems more likely that the oil should, by metamorphic circulation,[40] be concentrated from beds that are *known* to contain oil and flushed out a short distance along the bedding planes into the McMurray formation, than that it should have migrated from a distant and *purely hypothetical* source in the basal Cretaceous (somewhere between Athabaska and the Wainwright and Ribstone areas), through a lenticular series of sands and shales, to its present position in the McMurray formation.

The nature of the overlying Clearwater-Loon River shales and of the underlying Paleozoic limestone prevented their impregnation by petroleum; the impregnated body is, therefore, in the McMurray area at least, bounded above and below by these two formations. Further, the northward migration of petroleum was prevented by the Loon River shales, which directly overlie the Devonian in the northern part of the area and seal off the McMurray formation in that direction. Under this theory the shape and size of the resultant impregnated body is determined largely by the supply of hydrocarbons, the hydrostatic or other pressure, and the lithology and structure of the McMurray formation.

The flow of petroleum has now ceased or become greatly reduced, but it has not ceased to move. Percolating ground waters are facilitating the further movement of oil by increasing its fluidity, allowing for gravity and other adjustments to take place. A concentration of oil in the lower part of the McMurray formation, more or less regard-

[38] P. S. Warren, *op. cit.*

[39] See logs of wells Nos. 1 and 2, drilled by International Oils, Limited, at Lesser Slave Lake; and also logs of wells Nos. 1 and 2 drilled by the Athadome Oil Company, near Athabaska.

[40] E. M. Parks, *op. cit.*

less of the lithologic character, is the result of these gravity adjustments. The present existence of oil springs, due to supersaturation of the sands above impervious partings, is an example of such adjustments that are still taking place.

The theory of origin as here outlined is apparently in full harmony with the facts. The evidence in support of the idea may be summed up as follows.

First, the present outlines of the impregnated body point to the source as being northwest of McMurray. The absence of hydrocarbons from the McMurray formation near Athabaska Landing and from the same formation on the Clearwater River east of Cottonwood Creek bears witness to this. These areas are apparently outside the radius affected by the oil.[41] Supporting this contention also is the most significant fact that the oil from Ells River is more volatile and is lower in sulphur than that from any other known part of the area. Clark says[42]

> The bituminous sand from Ells River is exceptional in nature and stands in marked contrast with material from all other parts of the area. It looks different and it feels different. It is more like an oily sand than one impregnated with a sticky bitumen. A closer study of this section would be of much interest and might lead to information of both practical and theoretical significance.

Second, petroleum is reported from the upper part of the Grand Rapids formation in the vicinity of Athabaska. This petroleum is so closely similar in character to that from the McMurray formation that a common origin is at once suggested. According to the theory under consideration such petroleum is part of that which has risen to higher stratigraphic levels in the Cretaceous rocks, through cracks in the impervious shale beds. Heavy petroleum of similar composition also is found in the basal Cretaceous sands of the Peace River district. It is not unlikely that this also has an origin in common with the McMurray oil.

Third, the Devonian dolomites, containing oil, as they do at Athabaska, at Lesser Slave Lake, on the Peace River near Peace River Crossing and at Vermilion Chutes, at the west end of Great Slave Lake, and to a lesser extent on the Athabaska and Clearwater rivers near McMurray, provide potential source rocks. The failure to find oil in commercial quantities seems to be due rather to an absence of suitable structures than of source beds. Under such structural and lithological conditions as obtain it would be most peculiar

[41] S. C. Ells, "Exploration of Bituminous Sand Areas in Northern Alberta," *op. cit.*

[42] K. A. Clark and S. M. Blair, *op. cit.*

if the Devonian did *not* yield some of its oil to these porous sands.

Fourth, the absence of small fissures from outcrops of Devonian limestone throughout the oil sand area adds to the evidence that the petroleum, if it did come from below, entered at some restricted point or points rather than through numerous small springs scattered over the whole region.

DISCUSSION

MEMORANDUM *RE IN SITU* THEORY

S. C. ELLS, Department of Mines and Resources, Mines Branch, Ottawa (discussion received, May 30, 1938). During my extended sojourn in the McMurray area, I have not given serious thought to the origin of the bitumen associated with the bituminous sand. Other matters of a more practical nature were apparently of more importance. Nevertheless I have given some consideration to the problem discussed in Dr. Sproule's paper and incline to the view that the bitumen has origin *in situ*.

The *in situ* theory was first suggested during a visit by the writer to the Derna deposit in Transylvania in 1928. The opinion then formed was subsequently strengthened by discussions with A. Beeby Thompson, whose knowledge of the Derna occurrence is much more intimate than my own.

It is unnecessary to repeat the considerations as outlined in Mr. Thompson's comment and quoted by Dr. Sproule in his paper. I merely propose to note very briefly certain local factors which have a direct application to the origin of the McMurray deposit.

1. Judging by the many outliers of Athabaska sandstone which occur south and southwest of the main body, it is safe to assume that at one time these sandstones extended much farther south than at present. Erosion has washed enormous tonnages toward the north and toward the southwest. The original thickness of the Athabaska sandstone has been estimated at approximately 600 feet, and it may be assumed that this deposit was the source of the sand aggregate of the bituminous sand.

2. To the north of McMurray, large areas of wet muskeg some thousands of square miles in extent, extend eastward from Athabaska River. Still farther eastward (as from the 4th meridian) the drainage system has become more mature and the terrain is notably drier. It appears safe to assume, however, that before such improvement in drainage became effective, vast deposits of vegetable matter accumulated on the ancient surface of the Athabaska sandstone.

3. The present Athabaska valley south of McMurray is much younger than the larger Clearwater valley to the east. It is evident that at one time a very large volume of water flowed down the ancient Clearwater valley. Moreover, the current of the ancient river was, for the most part, undoubtedly swift. Even the present relatively mature river has a fall of 116 feet within a distance of 21 miles, and an estimated fall of more than 600 feet within a distance of 180 miles.

These three conditions are safe assumptions. They could have provided indefinitely large quantities of sand aggregate and of oil-forming vegetable matter. There was also an ample flow of rapidly moving water as a transporting medium.

Exposures of bituminous sand extend up Clearwater valley to a point about 30 miles east of McMurray. A few miles to the east the really rapid rise in the river grade commences. From this point impregnation of the McMurray formation virtually ceases.

We thus have as premises, denudation of Athabaska sandstone, transportation of great quantities of vegetable matter, an adequate volume of sufficiently rapid water, and a basin centering about McMurray. These are certain of the more important factors which appear to constitute an argument in favor of the *in situ* theory.

JOHN A. ALLAN, Department of Geology, University of Alberta, Edmonton, Alberta (discussion received, August 4, 1938). A correct interpretation of the origin of oil in the bituminous sands at McMurray is not due to a lack of explanations, opinions, or theories put forward by several who have spent a few days or weeks in the field on certain parts of the deposit. After 25 years on geological work in Alberta, much of this time on the geology of northern Alberta, and after numerous examinations of the bituminous sand deposits and the surrounding geology during the past 20 years, the writer does not presume to have solved the problem of origin of the deposits.

Mr. Sproule states that he "presents his own view as to the correct explanation of the genesis" of the bituminous sands, and then concludes that his view "is not offered as a complete treatise on the origin of the McMurray oil but merely as a further contribution to this interesting study." This contribution is interesting but not very convincing. Conclusions based on too indefinite or incomplete evidence leave the reader confused as to the issue. Possibly because of the short time spent in the field, or possibly because the field observations were too limited, Mr. Sproule has sketched somewhat incompletely the facts determined by Ells, Clark, Hume, McLaren, and others on the character of the McMurray formation.

Each writer seems to have found the extent of the outcrops of the bituminous sands to be different. Sproule says "the black oil sands are exposed on the banks of the Athabaska for 65 miles below McMurray," and "Upstream, southwest of McMurray, the oil sands crop out for about 38 miles." Ball says 65 miles north and 40 miles southwest and Hume records the outcrops as extending 76 miles north and 42 miles southwest of McMurray.[43] That given by Hume is considered to be the closest to the actual extent of the bituminous sand outcrops along the valley of Athabaska River.

The writer considers that the arguments put forward in opposition to previous theories formulated by several writers are in part by no means conclusive, nor can he agree with the arguments by Sproule in support of his own theory. One must conclude that the restatement of the views of Bell "have been brought forward and left incomplete pending further investigation."

It is suggested by Sproule that the petroliferous material in the bituminous sands has been derived from the underlying Devonian formations as suggested by Bell. It is 55 years since Bell stated that "the vast quantities of somewhat altered petroleum . . . have been derived from the Devonian limestones, immediately underlying them." Since that date (1883) many geological data have been obtained on the stratigraphy of northern Alberta. The writer has observed stains of oil in the Devonian strata immediately

[43] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 2 (February, 1935), p. 158, and a discussion by G. S. Hume, p. 167.

below the bituminous sands, caused by seepage from the sands. Furthermore, he has examined microscopically the Devonian and older strata below the bituminous sands, from the cores of four wells drilled for salt in the vicinity of McMurray, one of which penetrated the pre-Cambrian, but not the slightest indication of oil or other hydrocarbons was obtained in any of these cores. It is certain that the Paleozoic rocks older than those on the contact with the Lower Cretaceous in the vicinity of McMurray did not supply the bituminous material in the deposit.

Younger Paleozoic beds may occur to the south, and west and northwest from McMurray, but no one has yet recognized them except in the front ranges of the Rocky Mountains 400 miles southwest, and the *Spirifer disjuncta* zone in Vermilion Chutes on Peace River. No one has yet recorded finding any horizons in the Paleozoic which might be regarded as source beds for the bituminous material in the McMurray formation. One is not justified in assuming that any oil showing in the Grand Rapids sandstone above "275 feet" of impervious Clearwater shale, or any other horizon in the Cretaceous, has of necessity been derived from the same source beds as those which produced the oil in the McMurray formation. It would be just as illogical to say that since the oil at Waterton Lakes near the 49th parallel "is similar" to the oil at Fort Norman close to the Arctic Circle, therefore the same source beds have supplied the oil in both localities.

The bituminous sands are loose sand grains held together with petroliferous material, and, at least in some places, films of water. The writer has always held the opinion that the "oil" was introduced into much of the sand soon after the deposition of the sand and before sufficient geological time had elapsed to indurate the sand to a sandstone. The mummified wood fragments and tree trunks substantiate this view.

The writer was not aware that source beds had been determined in the Devonian in this part of Alberta of sufficient thickness and extent to supply all the petroliferous material in the McMurray formation. Unfortunately this point is not discussed in the paper.

There are several sound arguments put forward by Sproule to explain a Paleozoic source of the oil, but, on the other hand, there are also many factors as expressed by Sproule which "militate against" his explanation of Bell's original suggestion that the oil came from the underlying Devonian strata.

K. A. CLARK, Research Council of Alberta (discussion received, August 6, 1938). One like myself who has worked with the bituminous sands from other than the geological approach has nevertheless an interest in the geologist's concern about the origin of the great bulk of oil in this deposit. I appreciate Dr. Sproule's service in bringing together the results of geological thought about the problem as well as his own contribution toward the solution of it.

The difficulty of using the observed facts about the bituminous sand deposit in arguing for or against a theory of origin of the oil is that one can not be sure of their significance. For instance, Dr. Sproule draws attention to the fact that the oil in the neighborhood of Ells River is somewhat lower in sulphur and higher in volatile constituents than the oil elsewhere and infers that this fact points to a westerly point of entry of the oil into the sands rather than, say, a southerly one. But why should this inference be made? What obvious connection is there between a lower sulphur and higher volatile

content and the path of migration of the oil? The Ells River sands are very fine, containing from 30–60 per cent or more of particles passing the 200-mesh sieve and yet they are sandy enough to have allowed considerable oil impregnation. Adsorption of asphaltic material by this very fine aggregate would be a more direct explanation of the lighter character of the oil than one involving the location of its origin.

Near the end of his paper Dr. Sproule mentions a secondary movement of oil in the bituminous sands due to the influence of ground water which has caused a concentration of oil in the lower part of the deposit more or less regardless of the lithologic character of the beds. My observations indicate that there has been a gravitational concentration of oil in any thick, uniform massive lens of bituminous sand. Lenses of this sort are more characteristic of the lower part of the deposit than of the upper part but they do occur high up. And wherever they occur, the gravitational concentration of oil is restricted to the lens. Lean beds may occur immediately under it.

The movement of oil under the influence of ground water is of another sort. Seepages or tar springs result. These are in the nature of a water-drive. Considerable volumes of oil have been expelled from bituminous sand beds, probably coarse, open-grained ones, in this way. One hears stories from those who have drilled wells through the bituminous sands about the hole filling with the thick oil. In some cases there appears to be ground for believing that a slow movement of the viscous oil into the well has occurred due to a hydrostatic head of ground water pushing on the oil in a open-grained bed.

The origin of the oil in the bituminous sands will long continue to be a beautiful topic for geological debate. The available facts can be used for one argument or for another and proof or disproof of any theory is well hidden away. Further, the whole discussion is enveloped in the uncertainties about the generation of petroleum and how it migrates and accumulates.

J. C. SPROULE (discussion received, August 27, 1938). A letter received recently from Max W. Ball relative to the time of accumulation of oil in the McMurray formation has reminded me that I have overlooked a very substantial bit of evidence.

The strongest evidence against the *in situ* theory was found on Reid Creek, Firebag River, and on a small brook on the north bank of Clearwater River near the mouth of the Christina.

At the latter place there are oil-free concretions in oil-impregnated sands. The concretions, containing ferruginous and calcareous material in the matrix of sand, have grown there at some time subsequent to deposition of the sediments and prior to their impregnation by oil.

On Reid Creek, large concretionary bodies occur in a series of alternating layers of oil-impregnated and barren sands, the stratification of which may be traced into the interior of the concretions. A part of one of these structures is pictured on Plate XXXI in "Exploration of Bituminous Sand Areas in Northern Alberta," by S. C. Ells (*Mines Branch Investigations for 1931*). The mineral responsible for the concretions has since been leached out and the pore spaces filled with oil, indicating not only that the oil entered the sands subsequent to the formation of the concretions but subsequent also to the removal of original crystalline material from the concretions by percolating ground waters.

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REGIONAL VARIATIONS IN COMPOSITION OF NATURAL GAS IN APPALACHIAN PROVINCE[1]

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ABSTRACT

A study of the composition of natural gas in the Appalachian Province shows it to have certain definite regional variations.

The amounts of the various chemical identities that are present and their areal distribution are shown, (1) in detail for the Elk-Poca and Campbell Creek Oriskany sand fields, Kanawha County, West Virginia, (2) in partial detail for the entire Big Injun sand production in West Virginia, and (3) by a composite for all producing horizons in the Appalachian Province.

These regional variations are discussed in relation to structure, sedimentation, and regional metamorphism as indicated by carbon ratios based on coal.

The composition of natural gas offers criteria for prospecting for gas and oil, and indicates relative areal positions of gas and oil in a given reservoir.

INTRODUCTION

A detailed study of the composition of the natural gases by geological horizon and areal distribution in West Virginia[4] showed them to have definite regional variations. Since the gas produced in West Virginia equals more than half that of all the other Appalachian states combined, and since its gases come from about thirty different geologic horizons, it is believed that this work can be used as a criterion for the entire province. Many analyses were received from companies and State geologists of the other states, and data from these analyses have been plotted in order to draw conclusions for the Appalachian Province.

Numerous studies have been made concerning the origin of natural gas and petroleum, the methods of attack generally beginning with the possible original source material, both plant and animal, and following it through the necessary changes for the ultimate formation of gas and oil.

The carbon ratio theory of White[5] has been widely used to delineate areas favorable and unfavorable for the production of gas and oil in commercial quantities. So far as the writers are aware, the actual

[1] Read before the Association at New Orleans, March 17, 1938. Manuscript received, May 26, 1938.

[2] State geologist.

[3] Chemist.

[4] Paul H. Price and A. J. W. Headlee, "Physical and Chemical Properties of Natural Gas of West Virginia," *West Virginia Geol. Survey*, Vol. 9 (1937).

[5] David White, "Some Relations in Origin between Coal and Petroleum," *Jour. Washington Acad. Sci.*, Vol. 5 (1915), pp. 189–212.

composition of the natural gas and its areal distribution were neglected in the discussions of these theories.

Geology of Appalachian Gas and Oil Province

The Appalachian gas and oil province extends northeast-southwest along the Appalachian Plateau in a belt about 900 miles long, and varies from 100 to 200 miles in width. It includes fields in New York, Pennsylvania, eastern Ohio, West Virginia, eastern Kentucky, a few scattered fields in central Tennessee, and extends into northern Alabama where small quantities of gas have been obtained.

The region is underlain by 25,000–30,000 feet of sedimentary rocks, including coal, which range in age from Cambrian to Lower Permian. The sediments were derived largely from the east and southeast and were deposited in the Appalachian geosyncline, a subsiding marine basin, extending from Alabama to Canada. The subsidence of the geosyncline, which in general kept pace with the deposition of the sediments, was interrupted many times during the Paleozoic era by uplifts when parts of the basin were raised above sea-level and exposed to erosion. This differential subsidence and uplift produced sedimentary environments that were, at times, favorable, and at other times unfavorable, for the growth and preservation of organic materials which later might have been converted into gas and oil.

Deposition was culminated by the Appalachian revolution which brought the Permian to a close in this area. The orogeny acted as a tangential or horizontal thrust from the east or southeast, the same direction as the source of the sediments, which strongly deformed the area. Folding, with some faulting, was greatest on the east, with less and less intensity toward the Cincinnati arch.

The present structure of this province is a synclinorium which in the central part of the area is a broad spoon-shaped trough, known as the "Pittsburgh-Huntington basin" (Fig. 1). The central axis extends in a southwesterly direction through Pittsburgh, Pennsylvania, and a point south of Huntington, West Virginia. This axis is interrupted by the Burning Springs anticline, which trends north and south. Southwest of the Burning Springs anticline the central axis of the synclinorium is marked by the Parkersburg syncline. Northwestward the rocks rise toward the Cincinnati arch, a distance of 160–180 miles, at rates ranging from 20 to 60 feet to the mile. Southeastward the rocks rise toward the Appalachian structural front, a distance of 80–100 miles, at an average rate between 50 and 100 feet to the mile. The northwest flank of the basin is marked by only minor reversals,

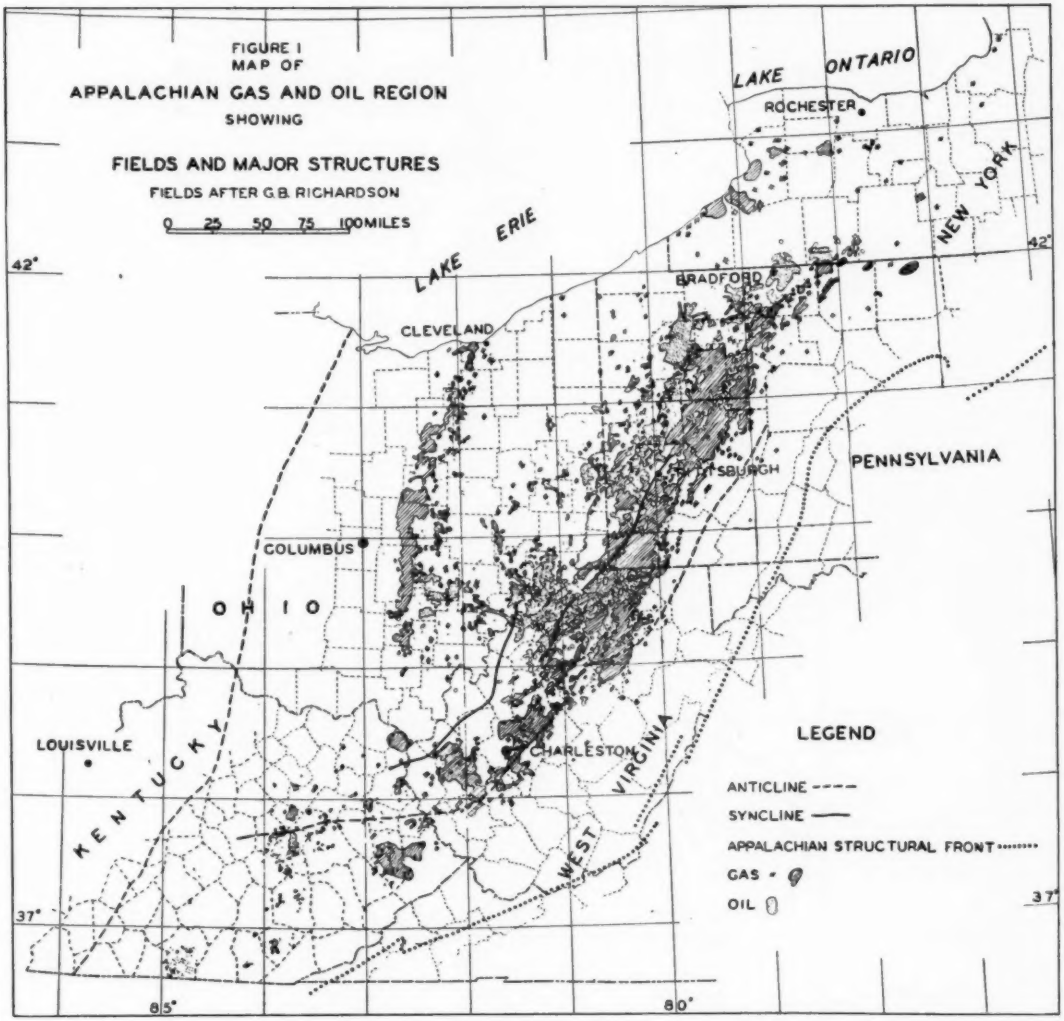
FIGURE 1
MAP OF
APPALACHIAN GAS AND OIL REGION
SHOWING
FIELDS AND MAJOR STRUCTURES
FIELDS AFTER G.B. RICHARDSON
0 25 50 75 100 MILES
LAKE ONTARIO
ROCHESTER
NEW YORK
LAKE ERIE
BRADFORD
CLEVELAND
PENNSYLVANIA
COLUMBUS
OHIO
LOUISVILLE
KENTUCKY
CHARLESTON
WEST VIRGINIA
42°
37°
85°
80°
LEGEND
ANTICLINE
SYNCLINE
APPALACHIAN STRUCTURAL FRONT
GAS
OIL

FIG. 1

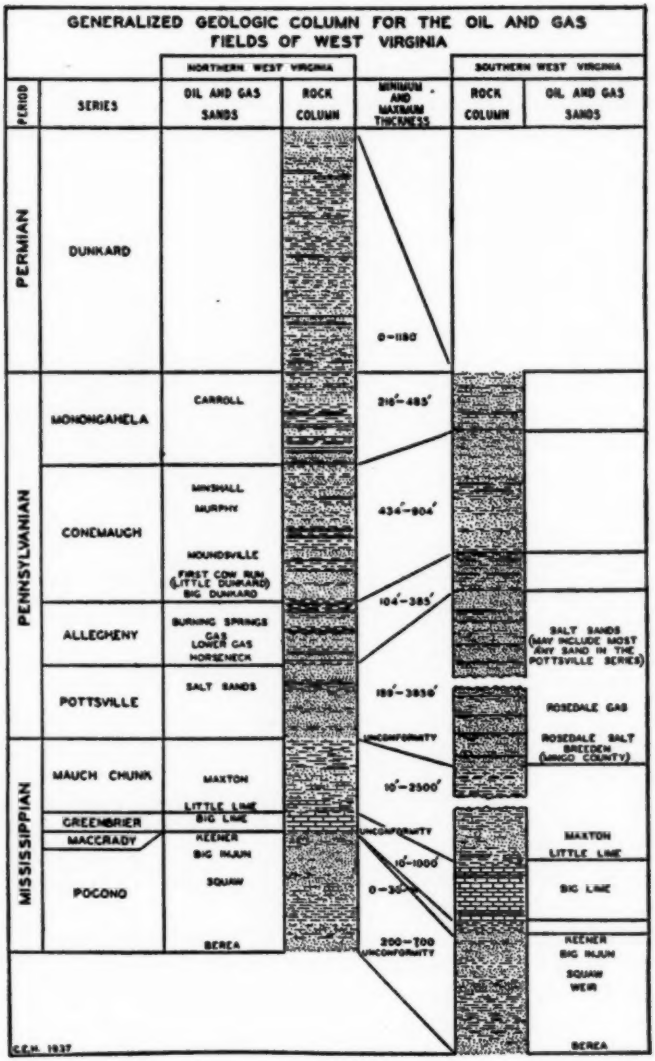
GENERALIZED GEOLOGIC COLUMN FOR THE OIL AND GAS FIELDS OF WEST VIRGINIA
NORTHERN WEST VIRGINIA
SOUTHERN WEST VIRGINIA
PERIOD
SERIES
OIL AND GAS SANDS
ROCK COLUMN
MINIMUM AND MAXIMUM THICKNESS
ROCK COLUMN
OIL AND GAS SANDS
PERMIAN
DUNKARD
0-1180
PENNSYLVANIAN
MONONGAHELA
CARROLL
215'-485'
CONEMAUGH
MINSHALL
MURPHY
MOUNDSVILLE
FIRST COW RUN (LITTLE DUNKARD)
BIG DUNKARD
434'-804'
ALLEGHENY
BURNING SPRINGS GAS
LOWER GAS
HORSENECK
104'-385'
SALT SANDS (MAY INCLUDE MOST ANY SAND IN THE POTTSVILLE SERIES)
POTTSVILLE
SALT SANDS
189'-3850'
ROSEDALE GAS
UNCONFORMITY
ROSEDALE SALT BREIDEN (MINGO COUNTY)
MISSISSIPPIAN
MAUCH CHUNK
MAXTON
LITTLE LIME
10'-2500'
GREENBRIER
BIG LIME
UNCONFORMITY
MAXTON
LITTLE LIME
MACCRADY
KEENER
BIG INJUN
10-1000
BIG LIME
POCONO
SQUAW
0-30
KEENER
BIG INJUN
SQUAW
WEIR
BEREA
200-700
UNCONFORMITY
BEREA
C.E.H. 1937

FIG. 2

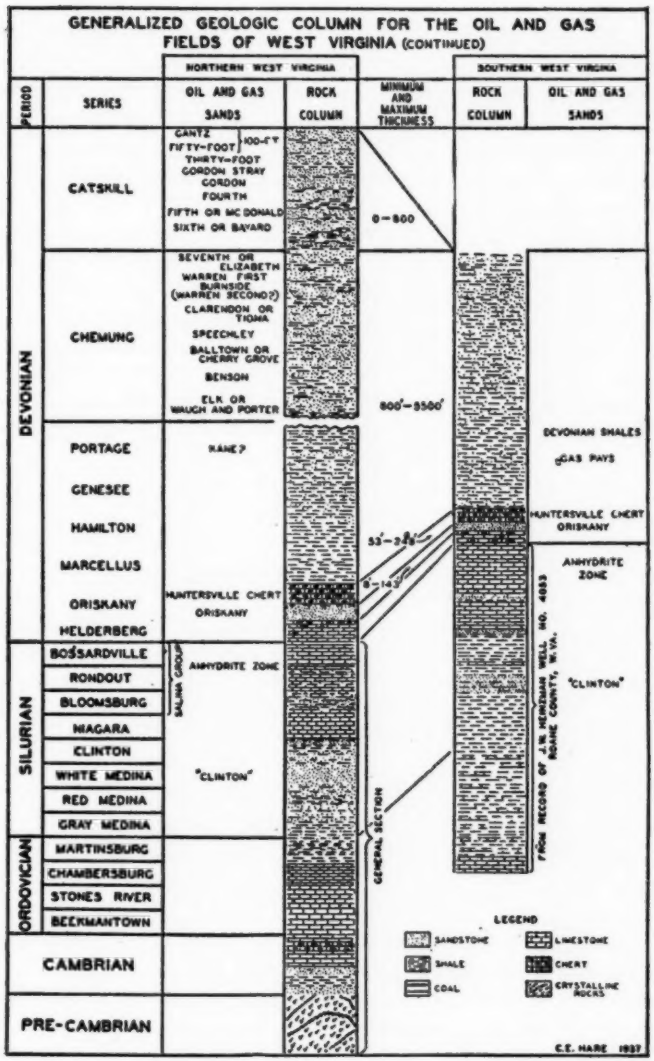

FIG. 2 (continued)

while the southeast flank is complicated by secondary folds that increase in intensity toward the east and are more numerous and pronounced in Pennsylvania and northern West Virginia than farther south. In southeastern Ohio, southwestern Pennsylvania, and northwestern West Virginia, beds of Permian age are surrounded by outcrops of beds of Pennsylvanian age, and along its western, northern, and eastern margins, Mississippian, Devonian, Silurian, and older rocks crop out in sequence. The areal distribution of the rocks indicates the general structure of the basin.

The gas and oil fields are, for the most part, elongate and generally occur in alignment with the major structural trends. The productive sands are commonly lenticular beds that presumably were deposited parallel to the old shore lines of the sea in which the sediments accumulated. Although some of the gas and oil sands maintain relative homogeneity over considerable areas—for example, the Big Injun sand of West Virginia—the sands in general are variable and within short distances merge with beds of different texture. The sands have pronounced variations in porosity and permeability, and differ in degree of cementation. Gas and oil occur in the more porous open parts of the beds, in places regardless of structure, and are absent in commercial quantities from the less porous tight parts. The number and stratigraphic position of the oil and gas sands are shown on Figure 2.

Where gas, oil, and water are all present, the gas tends to occur in the tops of domes, in the crests of anticlines, and in structurally higher parts of lenticular sands. The water tends to occur down the dip in structurally low parts of the beds, and oil, containing gas in solution, occupies an intermediate position between gas and water where all three are present in abundance. Where water is absent, oil may be found in the lower flanks of folds and in synclines. Numerous reservoirs are intimate mixtures of gas, oil, and water or, of only gas and oil, other pools having varying degrees of gravitational separation.

Analyses and Tests

On some 360 samples which included gas from wells producing from all the important gas horizons in West Virginia, the determinations made consisted of Podbielniak low temperature distillation analysis using liquid nitrogen as refrigerant; total heating value (Thv)[6] using Sargent automatic gas calorimeter; specific gravity by means of Headlee gas density balance; nitrogen from Thv-specific

[6] The total heating value is expressed in British thermal units per cubic foot, 30 inches *Hg*, 60°F. saturated with water vapor, and is abbreviated, Thv.

gravity data; carbon dioxide by absorption in potassium hydroxide; water vapor by psychrometer; oxygen by absorption in alkaline pyrogallol; and carbon monoxide and illuminants by palladium chloride. The tests for oxygen, carbon monoxide, and illuminants were negative in all cases. The analyses and tests received from other states were mainly "slow-combustion" analyses.

The regional variations are shown in terms of Thv calculated on the "inert free" or nitrogen and carbon dioxide free ("pure hydrocarbon") basis. A table is included for converting these iso-Thv lines into iso-carbon, iso-specific gravity, iso-methane, iso-ethane, et cetera, lines.

VALUES* FOR CONVERTING ISOMETRIC THV LINES INTO ISO-CARBON, ISO-SPECIFIC GRAVITY, ISO-METHANE, ET CETERA, LINES FOR "INERT FREE" NATURAL GAS

Thv	*Carbon (per cent) by Weight*	*Specific Gravity*	*Methane*† CH_4	*Ethane*† C_2H_6	*Propane*† C_3H_8	*Butanes*† C_4H_{10}	*Pentanes*† C_5H_{12}
996	74.87	.5544	100.0	.0	.0	.0	.0
1000	74.9	.5568	99.7	.3	.0	.0	.0
1050	75.2	.5890	95.7	2.8	.9	.4	.1
1100	75.4	.6214	91.5	5.4	1.8	.8	.3
1150	75.7	.6537	87.5	7.8	2.8	1.1	.4
1200	75.9	.6860	84	10	3.8	1.5	.5
1300	76.4	.7505	76	13	6	2.5	1.0
1400	76.8	.8150	69	16	9	3	1.7
1600	77.7	.9440	55	20	14	6	3

* Values are based on averages of 360 well sample analyses from West Virginia.
† Per cent by volume, "inert free."

ORISKANY HORIZON

GENERAL

Since several papers dealing with different phases of the Oriskany have recently appeared[7] no attempt will be made to consider it here other than that which applies directly to the subject under consideration.

The Oriskany[8] sand of the driller extends over the greater part of the northern half of the Appalachian Province as shown by numerous

[7] *Oriskany Sand Symposium* (Appalachian Geological Society, Charleston, West Virginia, 1937). Robert C. Lafferty, "The Oriskany in West Virginia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 2 (February, 1938), pp. 175–88.

[8] Paul H. Price, "The Oriskany Group (Areal) of West Virginia," *Oriskany Sand Symposium* (Appalachian Geological Society, 1937).

well logs and the many outcrops east of the Allegheny Front. Its areal distribution is outlined on Figure 17. The sand is light gray to white, medium to fine-grained, generally low in porosity, and varies from low to high calcium carbonate content, and in thickness from one to more than 100 feet.

KANAWHA COUNTY, WEST VIRGINIA

DEVELOPMENT

The United Fuel Gas Company's well No. 4067, south of Charleston, Kanawha County, West Virginia, 1930, with an initial open flow of about ½ million cubic feet, was the first commercial gas well in the Oriskany sand in the state. While several other wells drilled into the Oriskany sand during 1932–33 had showings or were only very light gassers, it was not until late in 1934 that the Burdette well, 6 miles northeast of Charleston, came in making both oil and gas. This is the only well to date that could be considered a commercial oil well. This completion inaugurated extensive drilling for Oriskany sand production in Kanawha County, which resulted in the development of the Campbell Creek and Elk-Poca fields. On February 15, 1938, 42 wells had been completed in the Campbell Creek field with an initial open flow of 68,252,000 cubic feet daily. On the same date, 158 wells had been completed in the Elk-Poca field with an initial open flow of 1,154 million cubic feet daily. From these two fields 61 well samples were analyzed. Only the wells from which samples were collected are shown on each of the figures on this field.

STRUCTURE, CHARACTER AND THICKNESS OF SAND

While structure contour maps prepared by others differ in detail, the general concepts are similar. A structure map on these fields based on records furnished the writers is shown by sub-sea-level contours on top of the sand (Fig. 3).

The sand is light gray to white, moderately to highly calcareous, but some of it, including the gas pay in some wells, is only slightly calcareous. Generally the highest portion of the calcium carbonate is toward the base of the formation grading into an impure limestone below. The texture of the quartz sand varies from medium to fine-grained for the most part, but there are occasional streaks of coarser material. The grain size is generally smaller toward the bottom. Lafferty[9] gives porosity based on scattered wells as ranging from 6.8 to 11 per cent.

In many wells total thicknesses were not available because the

[9] Robert C. Lafferty, *op. cit.*, p. 181.

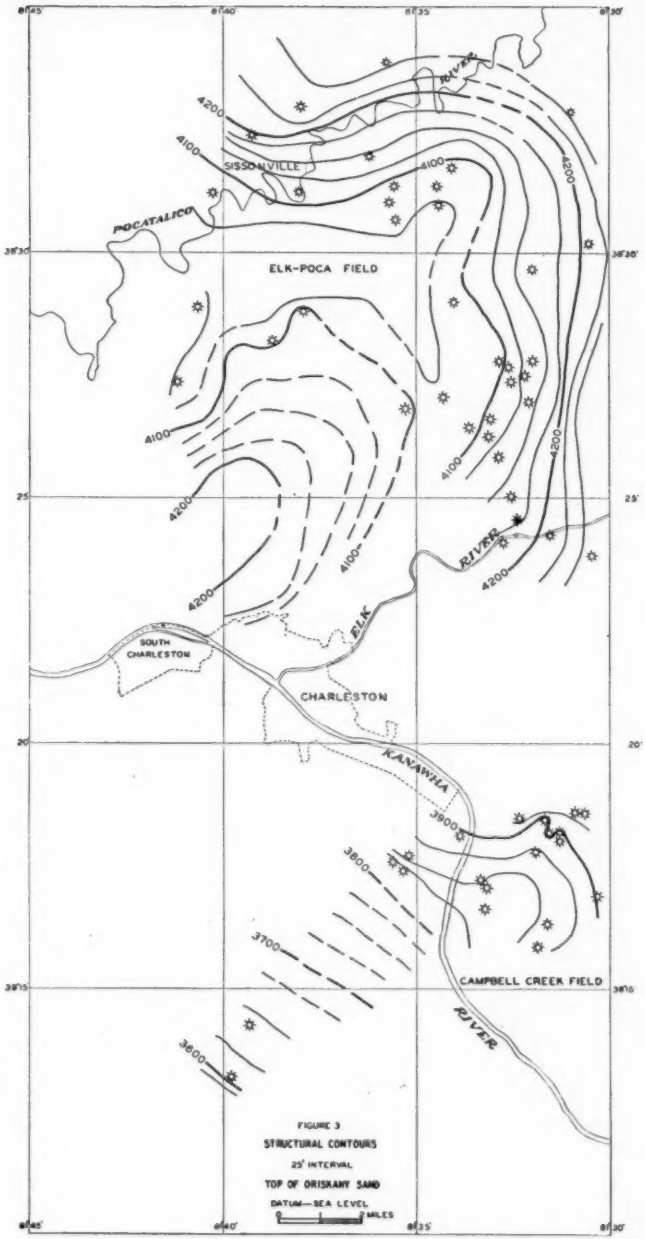
8°45'
8°40'
8°35'
8°30'
38°30'
38°25'
38°20'
38°15'
4200
4100
SISSONVILLE
POCATALICO
ELK-POCA FIELD
ELK
RIVER
SOUTH CHARLESTON
CHARLESTON
KANAWHA
3900
3800
3700
3600
CAMPBELL CREEK FIELD
FIGURE 3
STRUCTURAL CONTOURS
25' INTERVAL
TOP OF ORISKANY SAND
DATUM—SEA LEVEL
0 1 2 MILES

FIG. 3

entire sand was not drilled. An average thickness is approximately 30 feet.

OPEN-FLOW VOLUME IN RELATION TO STRUCTURE

While open-flow volumes were taken under varying conditions, some natural and others after shooting, some of which in each case may have been partly frozen off, nevertheless an open-flow map prepared from the best available data appears to be significant (Fig. 4).

COMPOSITION

The variation in the hydrocarbon content of the Oriskany gas is shown by a composition-Thv diagram (Fig. 5), in which the per cent by volume, inert free, of each hydrocarbon is plotted against the Thv, inert free. All the points for the hydrocarbons in any sample are located on the same Thv coördinate. It will be noted that as the Thv increases, the methane decreases, while the ethane, propane, butanes, pentanes, hexanes, heptanes, and higher boiling compounds increase in a uniform manner.

The areal distribution of these variations presents somewhat similar patterns which are shown on Figures 6 to 14 inclusive as isometric Thv and hydrocarbon lines. An examination of the Thv lines for the Campbell Creek field shows a progressive decrease in heating value from east to west, which is in this case up the dip. The heating values in this field range between 1,120 and 1,174 Btu, and, while showings of oil were found with the gas in several wells, none gave commercial oil production.

In the Elk-Poca field the Thv decreases in general away from the oil well. In the southern part of the field the Thv tends to decrease upslope while on the northern side the reverse is more generally true. The isometric methane lines (Fig. 7), have a pattern very similar to that of the Thv except that the values are in the reverse order, that is, low methane lines parallel high Thv lines; hence low methane values are found in the area around the oil. The isometric ethane, propane, butane, pentane, and hexane lines parallel those for Thv and are of the same general order. The variation in the amount of heptanes present in the Campbell Creek pool is not large enough to determine isometrically. In the Elk-Poca field the heptane content tends to decrease near the oil well. The decrease of the heptane and higher content of gas as oil is approached has been noted in wells from other horizons and is very likely due to the solubility of the heptanes and higher in the oil.

The octanes and higher content in the major part of the Campbell Creek field decrease in the reverse order to that of the ethane, pro-

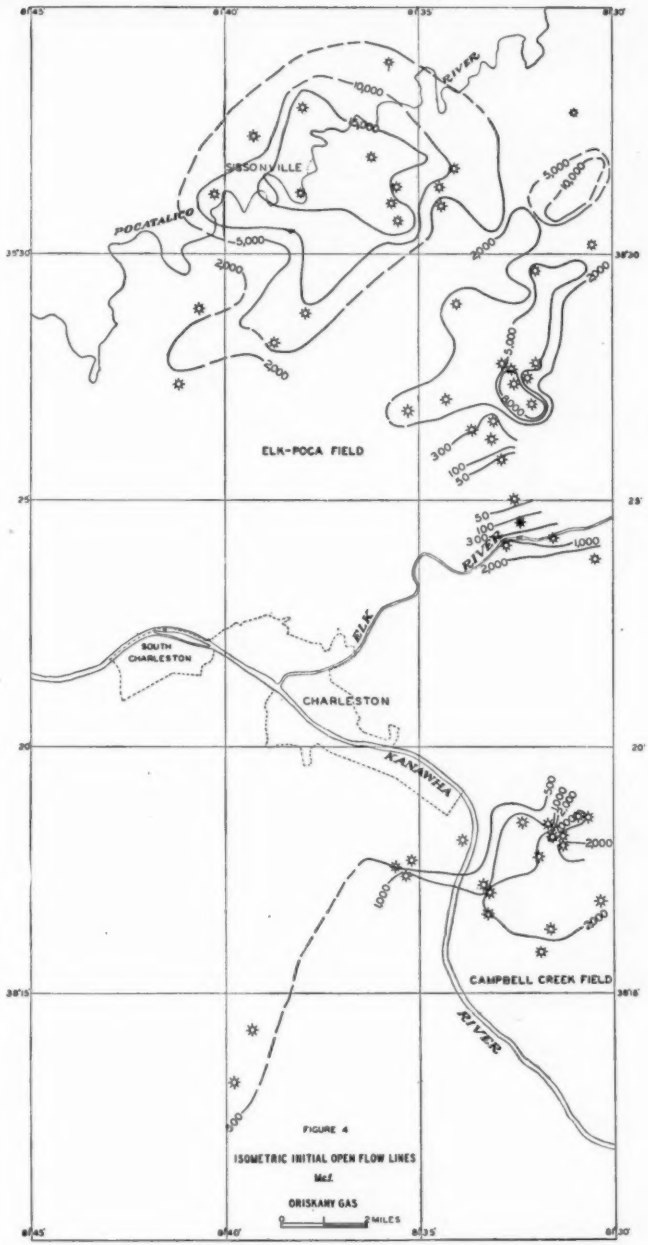
81°45'
81°40'
81°35'
81°30'
38°30'
38°25'
38°20'
38°15'
SISSONVILLE
POCATALICO
RIVER
10,000
5,000
2000
3,000
6,000
300
100
50
ELK-POCA FIELD
1000
ELK
SOUTH CHARLESTON
CHARLESTON
KANAWHA
CAMPBELL CREEK FIELD
500
FIGURE 4
ISOMETRIC INITIAL OPEN FLOW LINES
Mcf.
ORISKANY GAS
0 1 2 MILES

FIG. 4

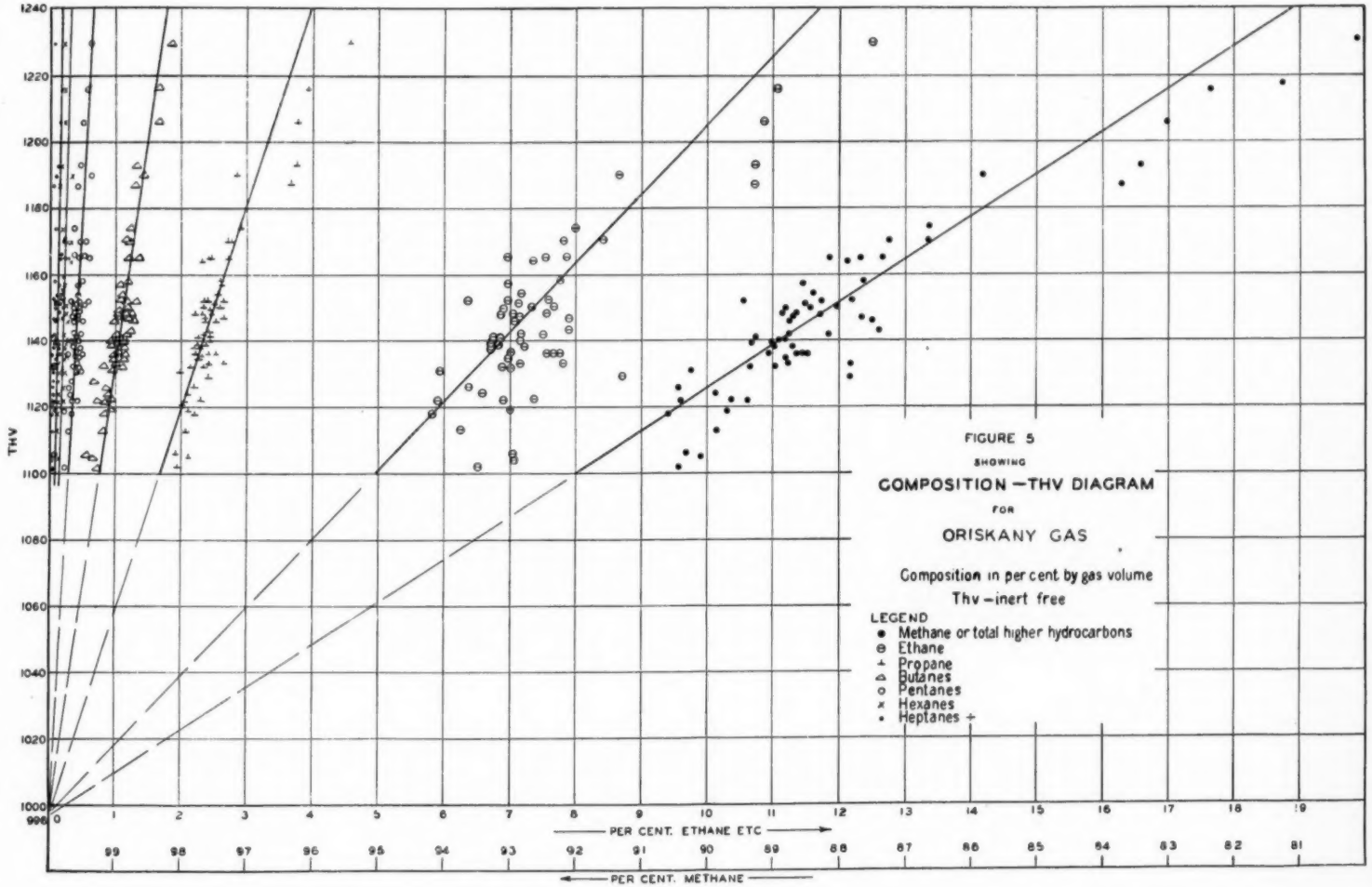
FIGURE 5
SHOWING
COMPOSITION —THV DIAGRAM
FOR
ORISKANY GAS
Composition in per cent by gas volume
Thv – inert free
LEGEND
Methane or total higher hydrocarbons
Ethane
Propane
Butanes
Pentanes
Hexanes
Heptanes +
THV
PER CENT. ETHANE ETC
PER CENT. METHANE

FIG. 5

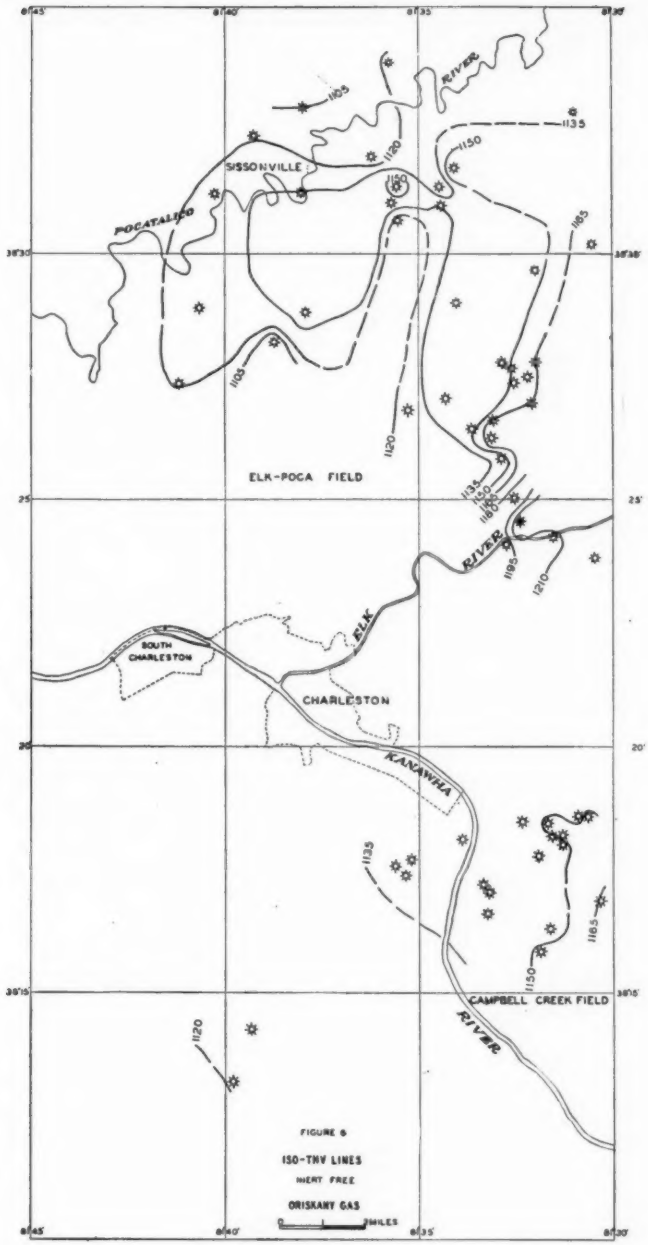
81°45'
81°40'
81°35'
81°30'
38°30'
38°25'
38°20'
38°15'
SISSONVILLE
POCATALICO
ELK-POCA FIELD
ELK RIVER
KANAWHA RIVER
SOUTH CHARLESTON
CHARLESTON
CAMPBELL CREEK FIELD
1105
1120
1135
1150
1165
1180
1195
1210
FIGURE 6
150-TNV LINES
INERT FREE
ORISKANY GAS
0 1 2 MILES

FIG. 6

FIG. 5

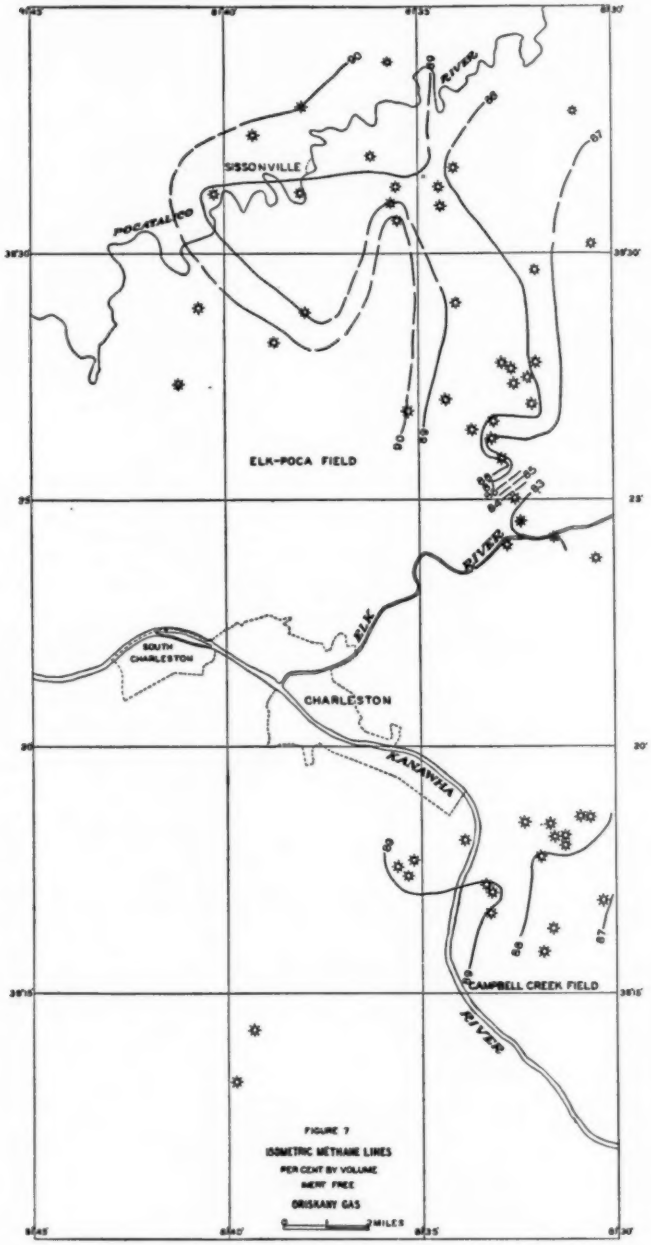
SISSONVILLE
POCATALICO
RIVER
ELK-POCA FIELD
ELK
RIVER
SOUTH CHARLESTON
CHARLESTON
KANAWHA
CAMPBELL CREEK FIELD
RIVER
FIGURE 7
ISOMETRIC METHANE LINES
PER CENT BY VOLUME
INERT FREE
ORISKANY GAS
0 1 2 MILES

FIG. 7

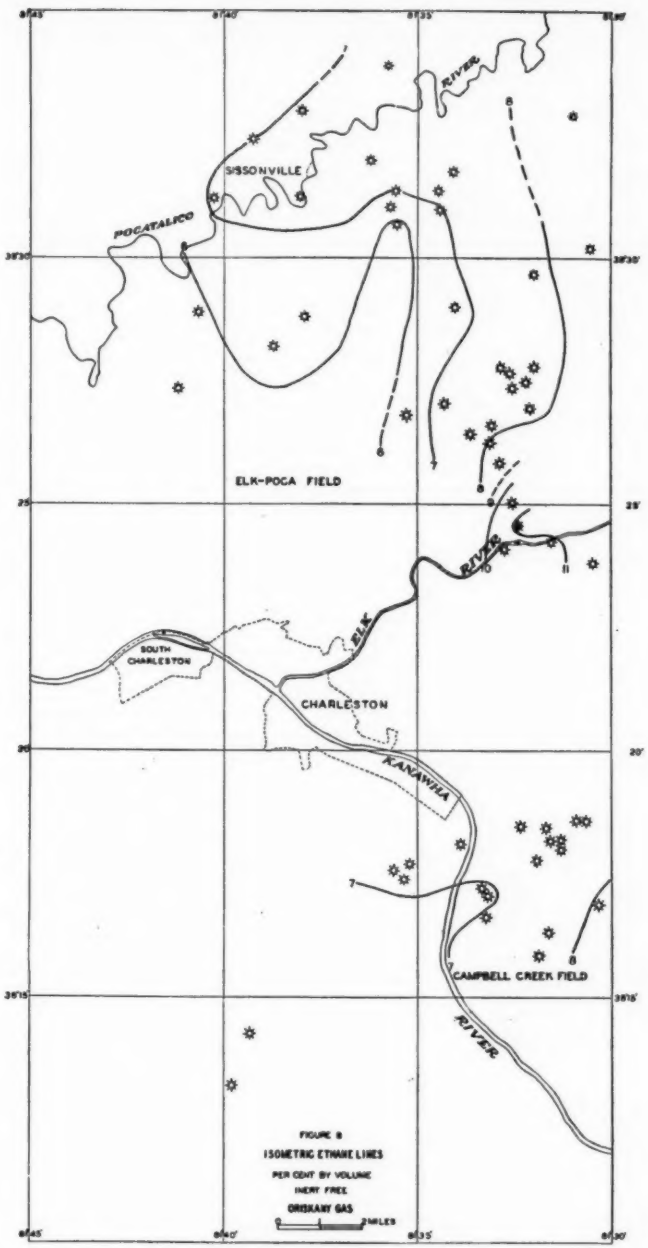
SISSONVILLE
POCATALICO
ELK-POCA FIELD
ELK RIVER
SOUTH CHARLESTON
CHARLESTON
KANAWHA
CAMPBELL CREEK FIELD
RIVER
FIGURE 8
ISOMETRIC ETHANE LINES
PER CENT BY VOLUME
INERT FREE
ORISKANY GAS
0 1 2 MILES

FIG. 8

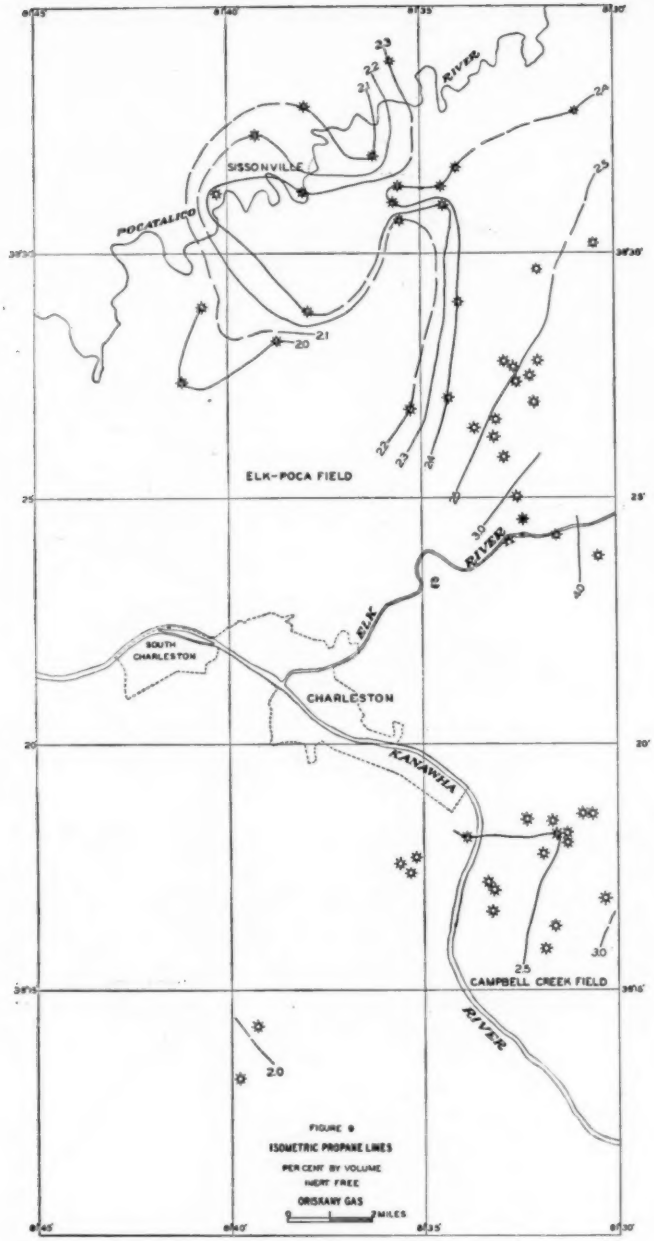
SISSONVILLE
POCATALICO
ELK-POCA FIELD
ELK RIVER
SOUTH CHARLESTON
CHARLESTON
KANAWHA
CAMPBELL CREEK FIELD
RIVER
FIGURE 9
ISOMETRIC PROPANE LINES
PER CENT BY VOLUME
HEAT FREE
ORISKANY GAS
0 1 2 MILES

FIG. 9

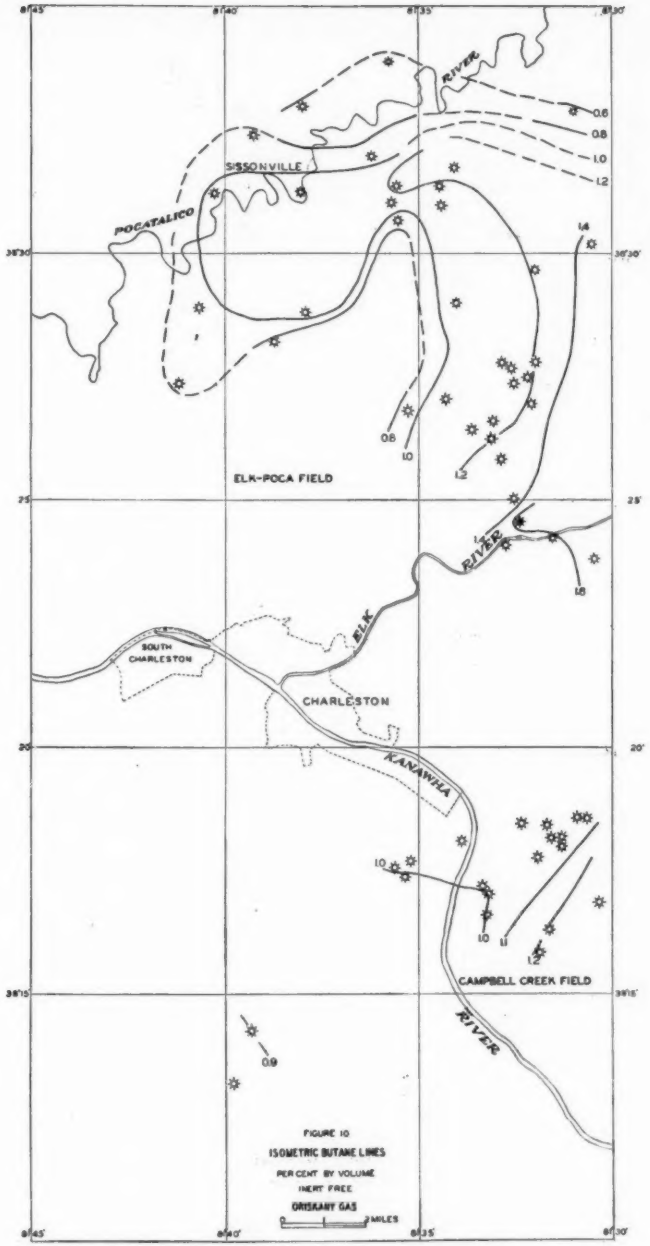
RIVER
0.6
0.8
1.0
1.2
SISSONVILLE
POCATALICO
1.4
0.8
1.0
1.2
ELK-POCA FIELD
1.4
RIVER
1.6
ELK
SOUTH CHARLESTON
CHARLESTON
KANAWHA
1.0
1.0
1.1
1.2
CAMPBELL CREEK FIELD
RIVER
0.9
FIGURE 10
ISOMETRIC BUTANE LINES
PER CENT BY VOLUME
INERT FREE
ORISKANY GAS
0
1
2 MILES

FIG. 10

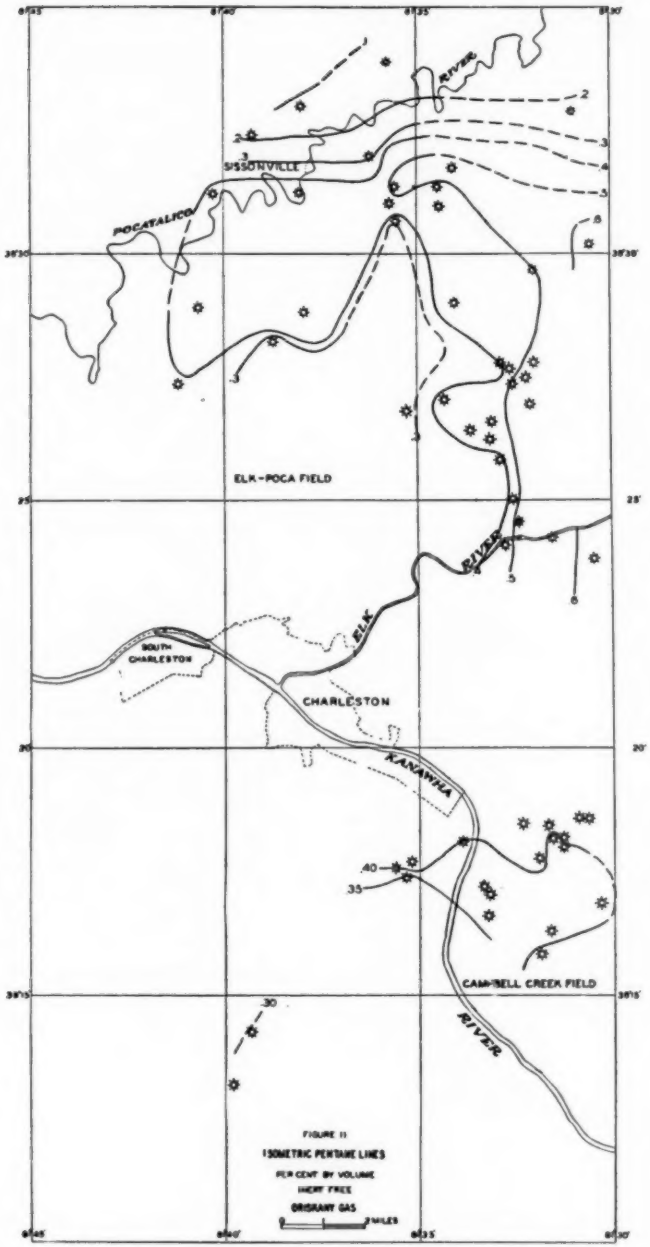
SISSONVILLE
POCATALICO
ELK-POCA FIELD
ELK RIVER
SOUTH CHARLESTON
CHARLESTON
KANAWHA
CAMPBELL CREEK FIELD
RIVER
FIGURE 11
ISOMETRIC PENTANE LINES
PER CENT BY VOLUME
INERT FREE
ORSAT ANY GAS
0 1 2 MILES

FIG. 11

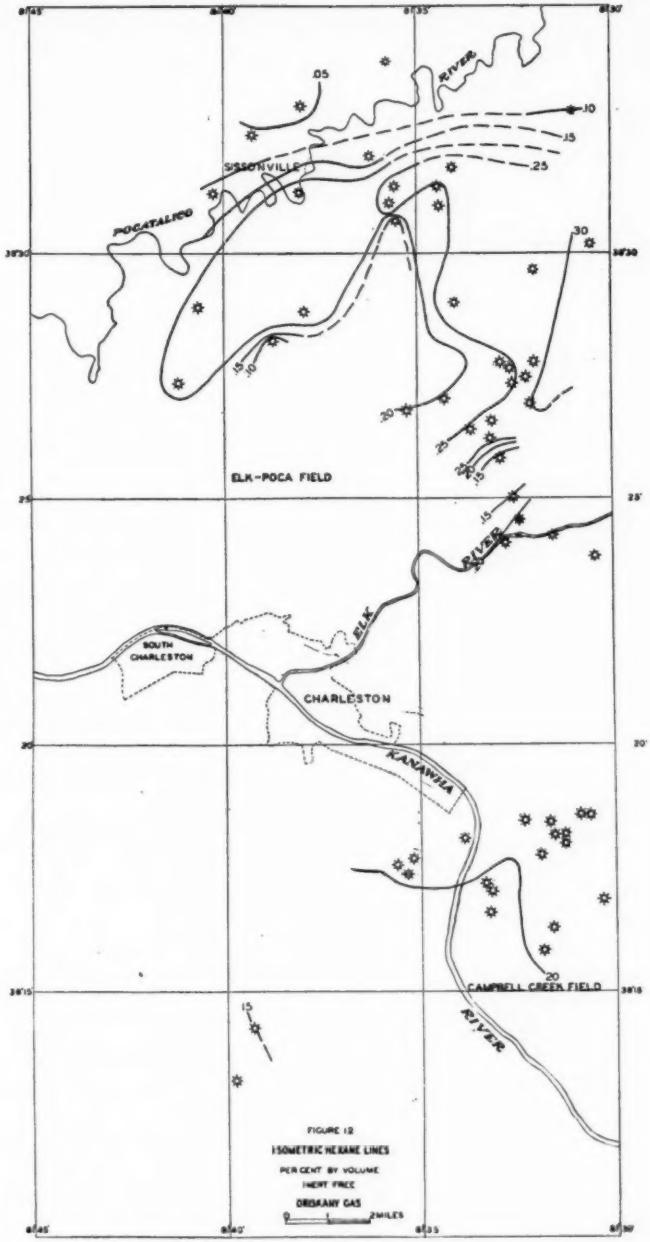
.05
.10
.15
.25
.30
SISSONVILLE
POCATALICO
ELK-POCA FIELD
ELK RIVER
SOUTH CHARLESTON
CHARLESTON
KANAWHA
CAMPBELL CREEK FIELD
RIVER
FIGURE 12
ISOMETRIC HEXANE LINES
PER CENT BY VOLUME
INERT FREE
ORSAANY GAS
0 1 2 MILES

FIG. 12

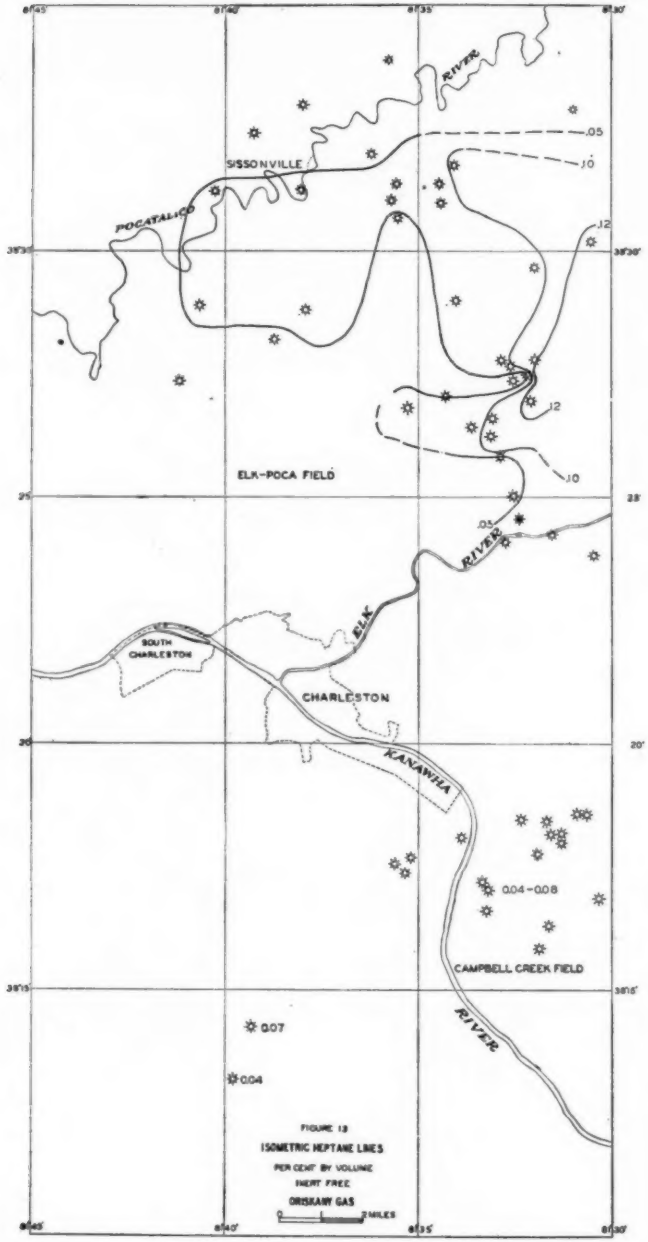
RIVER
.05
SISSONVILLE
.10
POCATALICO
.12
38°30'
.12
.10
ELK-POCA FIELD
.05
RIVER
ELK
SOUTH CHARLESTON
CHARLESTON
KANAWHA
0.04-0.08
CAMPBELL CREEK FIELD
38°15'
RIVER
0.07
0.04
FIGURE 13
ISOMETRIC HEPTANE LINES
PER CENT BY VOLUME
INERT FREE
ORISKANY GAS
0
1
2 MILES

FIG. 13

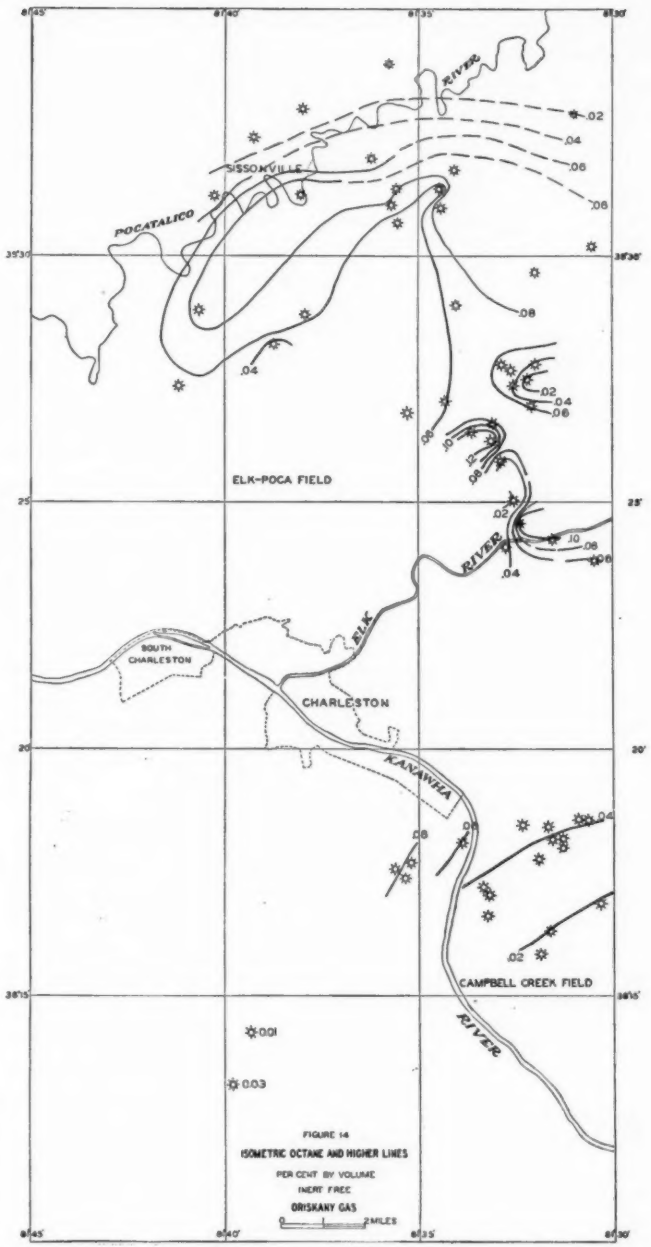
8°45'
8°40'
8°35'
8°30'
RIVER
.02
.04
.06
.08
SISSONVILLE
POCATALICO
38°30'
.08
.04
.02
.04
.06
.08
.10
.12
.08
ELK-POCA FIELD
25'
.02
.10
.06
.08
.04
RIVER
ELK
SOUTH CHARLESTON
CHARLESTON
20'
KANAWHA
.08
.08
.04
.02
CAMPBELL CREEK FIELD
38°15'
.001
.003
RIVER
FIGURE 14
ISOMETRIC OCTANE AND HIGHER LINES
PER CENT BY VOLUME
INERT FREE
ORISKANY GAS
0 1 2 MILES

FIG. 14

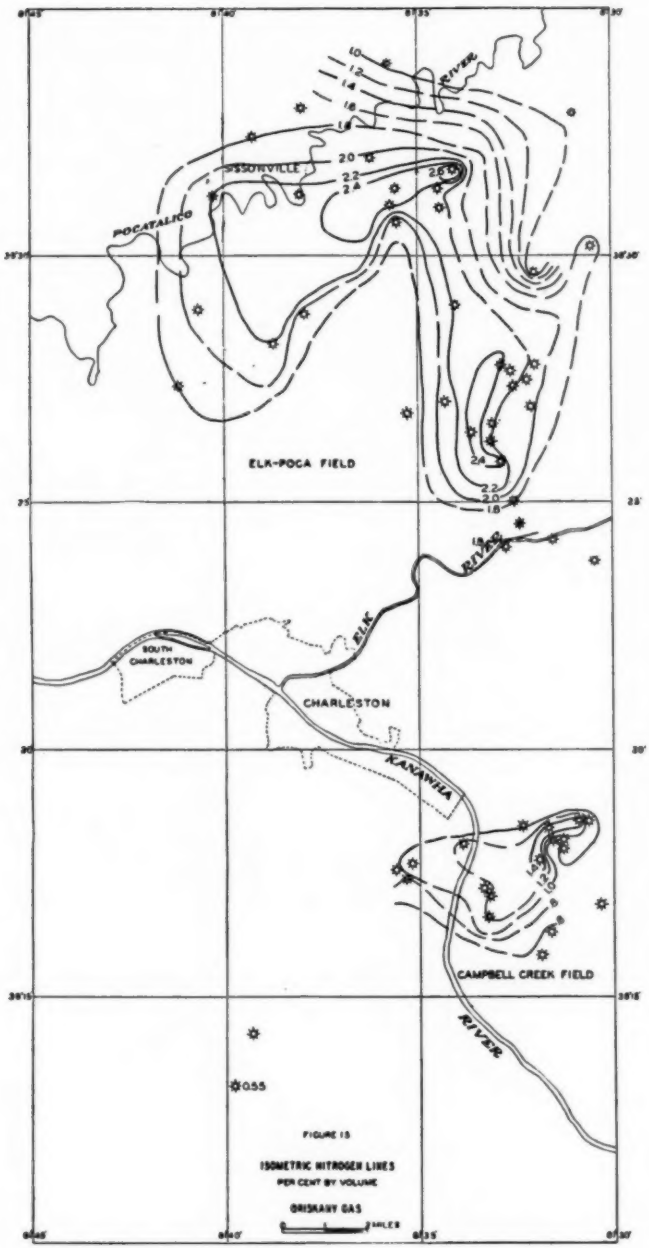
ELK-POCA FIELD
CHARLESTON
SOUTH CHARLESTON
CAMPBELL CREEK FIELD
POCATALICO
ELK
KANAWHA
RIVER
0.55
FIGURE 15
ISOMETRIC NITROGEN LINES
PER CENT BY VOLUME
ORISKANY GAS

FIG. 15

pane, butanes, and pentanes. The lines are similar to those for the other higher hydrocarbons in the Elk-Poca field except in the southeastern part. The age of the well and the conditions under which it has been and is being produced affect the amount of octanes and higher that are included in the sample.

The gravities of the naphtha produced by the wells in the western part of the Elk-Poca field vary in a manner similar to that of the Thv's. Data are not available for wells in other areas.

The nitrogen content, shown on Figure 15, is highest in the northeastern part of the Campbell Creek field, decreasing in per cent from 1.5 to 0.5 toward the southwest or upslope. In the Elk-Poca field, the high nitrogen area is L-shaped, broadening out in the Sissonville area, roughly paralleling the 4,100-foot contour, and decreasing in value away from this high. As in the case of the higher hydrocarbons, the nitrogen decreases rapidly to the north.

The gas in the Campbell Creek field contains much more carbon dioxide than is ordinarily found associated with the gas in the Appalachian region (Fig. 16). The isometric carbon-dioxide lines are transverse to the lines for the other constituents as well as to the structure contours. Some geologists have associated the carbon-dioxide content with faulting in this area. The range in values for the Elk-Poca field was too low (0.005–0.03 per cent carbon dioxide) for isometric determination. It appears that in the Campbell Creek field where the carbon dioxide is high, the nitrogen is low; while in the Elk-Poca field the reverse is true, thereby tending to equalize the effects of inerts on heating value.

TOTAL HEATING VALUES FOR ORISKANY FIELDS

Oriskany sand gas production is now known from several fields located in such a manner as to outline its wide areal distribution. Analyses from these fields where available are shown on Figure 17 along with the locations of most of the fields. Sufficient data were not available to isometer the entire area, but it is worthy of note that the low Thv, high methane gases follow the margin of the present outer limits of production, while the Thv's increase and the methane decreases toward the center of the basin.

Big Injun Sand

The Big Injun sand (Burgoon of Pennsylvania), coming near the top of the Pocono, is the most widespread and consistently producing horizon for both oil and gas in the Appalachian Province. It is recognized as a producing sand in parts of four states: southwest Penn-

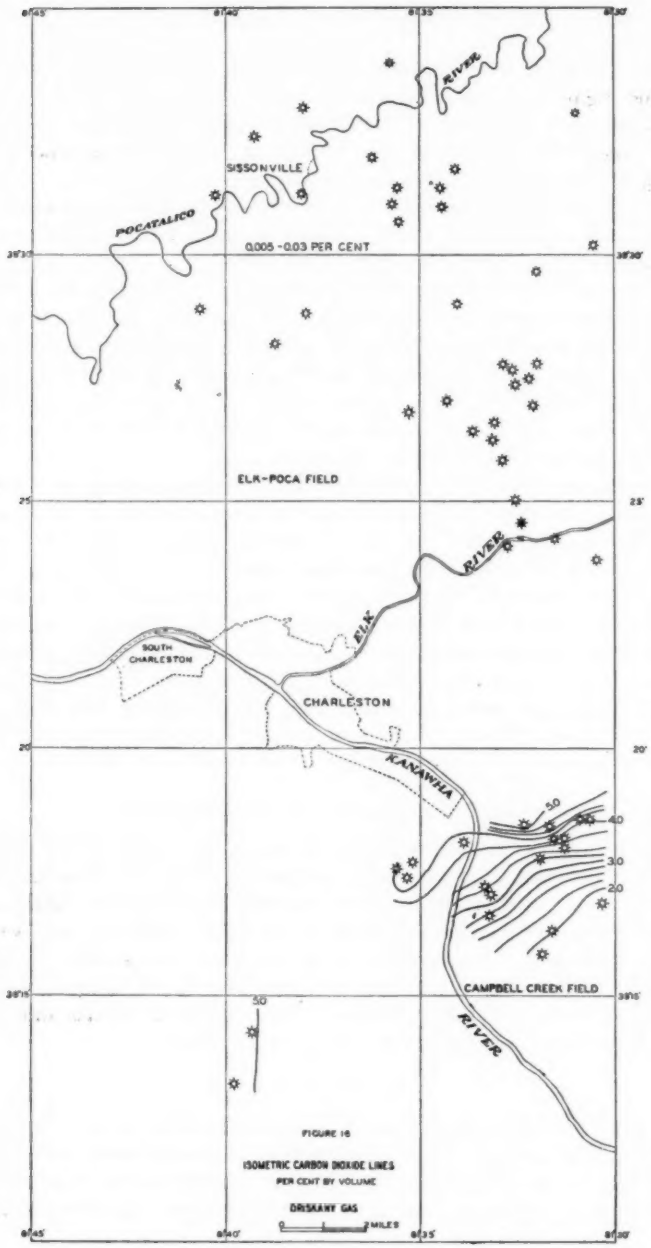
RIVER
SISSONVILLE
POCATALICO
0.005 -0.03 PER CENT
ELK-POCA FIELD
RIVER
ELK
SOUTH CHARLESTON
CHARLESTON
KANAWHA
5.0
4.0
3.0
2.0
1.0
CAMPBELL CREEK FIELD
RIVER
5.0
FIGURE 16
ISOMETRIC CARBON DIOXIDE LINES
PER CENT BY VOLUME
DRISKANY GAS
0 1 2 MILES

FIG. 16

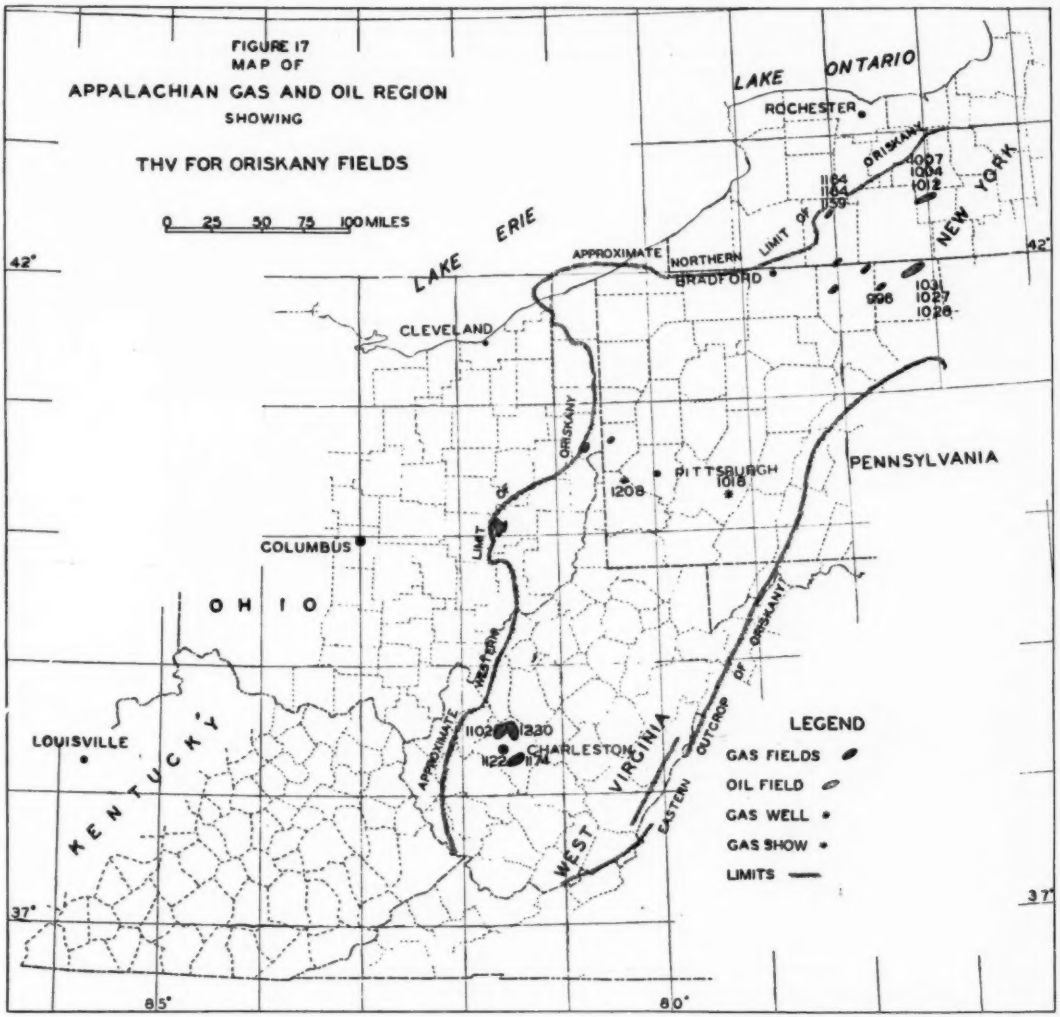
FIGURE 17
MAP OF
APPALACHIAN GAS AND OIL REGION
SHOWING
THV FOR ORISKANY FIELDS
0 25 50 75 100 MILES
LAKE ONTARIO
ROCHESTER
ORISKANY
1027
1004
1012
1164
1164
1159
NEW YORK
LAKE ERIE
APPROXIMATE NORTHERN LIMIT OF ORISKANY
BRADFORD
996
1031
1027
1028
42°
CLEVELAND
PITTSBURGH
1018
1208
PENNSYLVANIA
COLUMBUS
APPROXIMATE WESTERN LIMIT OF ORISKANY
OHIO
OUTCROP OF ORISKANY
LOUISVILLE
1102
1220
1122
1174
CHARLESTON
KENTUCKY
WEST VIRGINIA
EASTERN
LEGEND
GAS FIELDS
OIL FIELD
GAS WELL
GAS SHOW
LIMITS
37°
85°
80°

FIG. 17

sylvania, western West Virginia, eastern Ohio, and eastern Kentucky. In West Virginia alone this horizon accounted for about 25 billion

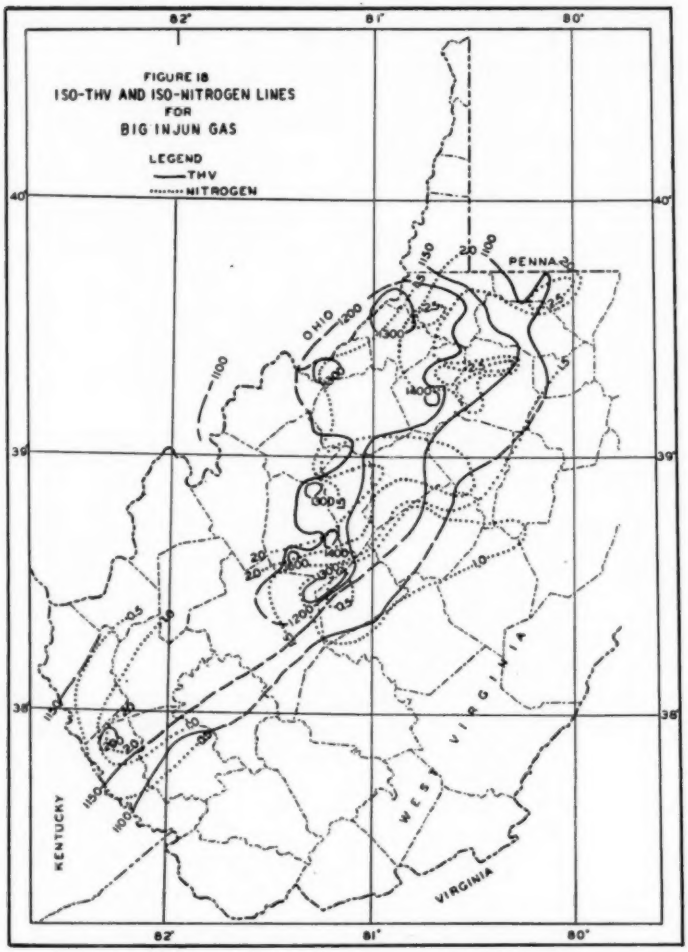

FIG. 18

cubic feet of natural gas during 1934. Because of the widespread production of gas from this horizon, it offered what appeared to be the most logical single sand from which the composition of a gas over

wide areas could be studied. The sand is in few places massive in character, being in general, thin- and cross-bedded, with quantities of plant material developing into thin coals, all of which suggest shallow-water deposition. In this sand a variety of textural conditions are found, varying from shaly through fine, to medium and coarse-

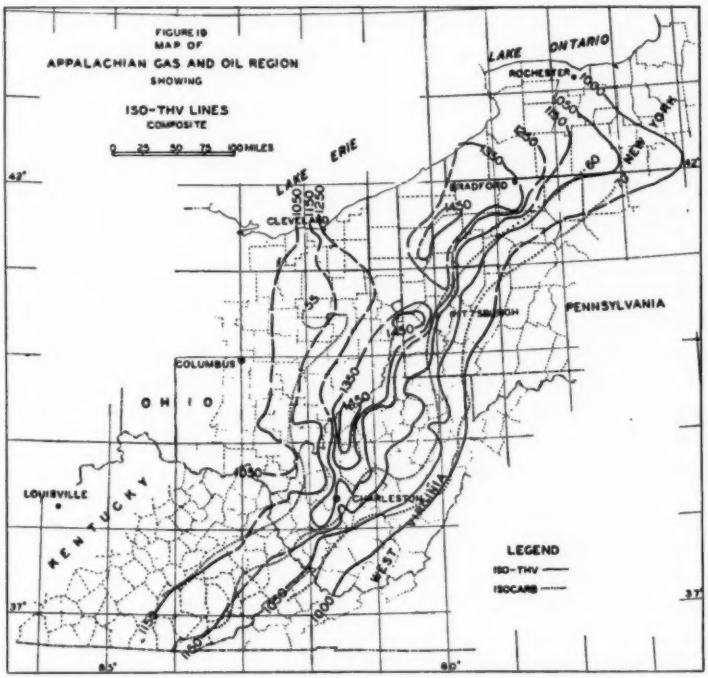

FIG. 19

grained, and in places conglomeratic. It varies in thickness from a few feet in some areas to a maximum of 300 feet in northern West Virginia.

COMPOSITION OF BIG INJUN GAS

An isometric Thv and nitrogen map (Thv solid and dashed lines, nitrogen dotted lines) for Big Injun gas has been prepared, based on analyses of 87 samples from wells selected so as to include the largest possible areal distribution (Fig. 18). Although the majority of the samples were collected in West Virginia, they are so distributed as to

cover the greater part of the fields. Production in this horizon occurs in a northeast-southwest belt paralleling the major structural trends of the region. The iso-Thv lines align themselves in a similar manner, increasing in value as the center of the basin is approached, and conversely, decreasing in value away from a series of localized highs; all of which occur in a general alignment in northeast and southwest directions. In general, these localized high Thv's come from wells producing oil and in close proximity to oil production. It should be noted that the oil production is limited to the central part of the basin and flanked on all sides by gas.

The nitrogen content of Big Injun gas is ordinarily low, being in most places less than two per cent. While contours have been drawn to show the regional variation in nitrogen content, there appears to be no definite relationship between them and Thv's.

AVERAGE COMPOSITION OF ALL GASES IN APPALACHIAN REGION

A map has been prepared (Fig. 19) of the Appalachian gas and oil region showing Thv's of gases from all important producing horizons. It is a composite of analyses from 334 well samples from West Virginia, 36 wells and 6 fields of Ohio, 35 wells and 10 fields of Pennsylvania, 12 wells and 1 field of New York, and 15 wells of Kentucky. All Thv's were computed to inert free basis.

The iso-Thv lines ranging from above 1,450 to 996 Btu, or pure methane, again fall in a northeast-southwest pattern definitely paralleling the alignment of the major geologic structure and even conforming with the salients and recesses of Keith[10] for the Appalachian Mountains. The Thv highs align themselves in a similar manner and fall generally along the central axis of the basin. There is a definite, progressive decrease in Thv as the border of the producing area is approached, in all directions.

Although isometric methane lines are not shown, analyses prove that they are in the reverse order to the Thv's, the low methane paralleling the high Thv's and the high methane paralleling the low Thv's. With the higher hydrocarbons the reverse is true, that is, large amounts of higher hydrocarbons parallel the high Thv's and small amounts parallel the low Thv's.

On the composite Thv map isocarbons (55–70) based on coal have been included for the gas- and oil-producing area in order to show the progressive devolatilization of coal due to dynamic influences. It may be noted that a decrease in fixed carbon or an increase

[10] Arthur Keith, "Outlines of Appalachian Structure," *Bull. Geol. Soc. America*, Vol. 34 (June, 1933), pp. 309–80.

in volatile matter is shown away from the highly deformed area.

If the Thv lines on gas are converted into iso-carbon lines, a different arrangement is seen. It shows that the iso-carbon lines as based on gas decrease in value in all directions, away from a central high axis which coincides with the high Thv's.

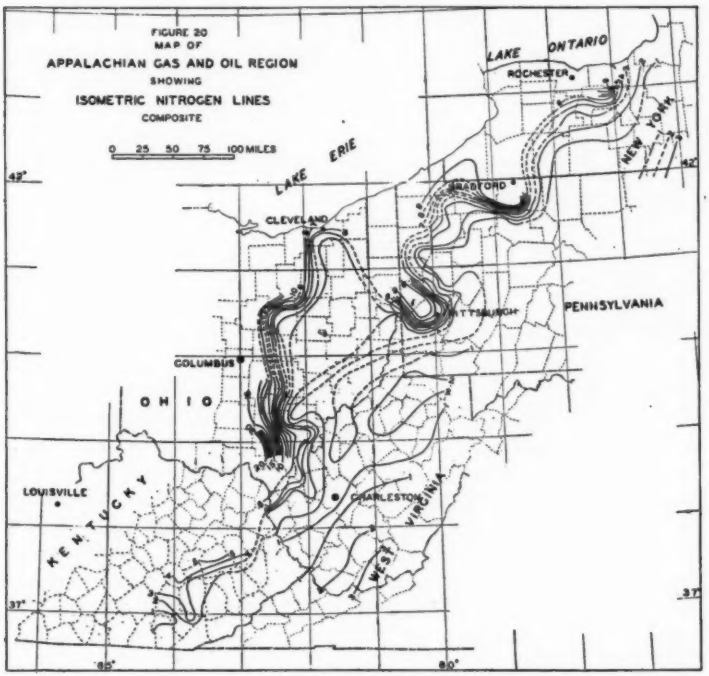

FIG. 20

NITROGEN

Nitrogen (Fig. 20) content based on the average of many analyses of gases from different horizons and fields possibly does not present a very reliable picture. Furthermore, many of the analyses from states other than West Virginia represent data from older methods of sampling and analysis. However, as many data were available, an attempt was made to use an isometric determination to show regional variations. While the writers appreciate its shortcomings, from the present available data it is offered for any value it may have. There are, however, definite, high nitrogen areas.

Although helium was not determined in samples analyzed in the writers' laboratory, its common association with high nitrogen is generally recognized.[11]

Summary

It can be seen from the preceding remarks that a great quantity of detailed data on the composition of natural gas in the Appalachian Province, including fields covering a wide variety of conditions, has been given. Just what these results mean and what may be inferred from them regarding the occurrence of both oil and gas, is yet in the developmental stage. That gases of certain composition in a given horizon, where oil is also present, lie in relatively fixed positions with the oil, and also lie within certain fixed regional structural limits, is very strongly indicated.

Although the sedimentary environment, with special reference to plant and animal life, depth of water, relation to shore line, *et cetera*, for those horizons containing gas and oil is not well known, the environment of recent sediments has received considerable attention. Trask[12] has shown that the organic content of recent sediments depends on the configuration of the sea bottom, depressions and basins favoring its accumulation, and ridges and slopes hindering its deposition. In general, the greatest amount of organic material will be found near the shore; the submarine topography, sea currents, depth of water, *et cetera*, controlling the areal distribution of the organic material. There is no reason why ancient sedimentary environment should have been radically different from that at the present time and it is believed by the present writers that if an accurate reproduction of the environment of a former depositional area could be had, in connection with its subsequent structural history, it would offer the greatest possible aid in locating the present position of gas and oil.

Because of the many similar conditions and circumstances that existed throughout the period of deposition of the gas- and oil-bearing sediments, this regional Thv map should also hold in a general way for all the horizons composing it. Ever changing shore lines, sea currents and depths, and changing physiographic and topographic features of the basin (both sea floor and land) have caused considerable lateral variation in locations favorable to the formation and accumulation of gas and oil in the horizons composing the geologic column. Iso-Thv maps for several horizons in West Virginia show

[11] G. S. Rogers, "Helium-Bearing Natural Gas," *U. S. Geol. Survey Prof. Paper 121* (1921).

[12] Parker D. Trask, *Origin and Environment of Source Sediments of Petroleum* (Gulf Publishing Company, Houston, Texas, 1932).

trends similar to those on the regional map. However, high or low Thv areas in one horizon do not necessarily indicate similar areas in the horizons above or below; hence prospective areas for gas and oil are indicated only by iso-Thv lines for that particular horizon.

The highs for the Thv's (Fig. 19) parallel the basin and are located in its central part; the other values decreasing in all directions from these highs. The gases decrease in Thv and approach pure methane from the central part of the synclinorium toward the Appalachian structural front, also toward the Cincinnati arch, and toward the northern and southern ends of the structural basin. Converting these Thv lines to iso-carbon lines, those east of the center of the basin are in the reverse order of carbon ratios for coal; the low carbon, high volatile gases are the most eastern while the high carbon, low volatile coals are the most eastern. The analyses show that the iso-carbon lines also decrease westward from the center of the basin and that there are low carbon, high volatile gases on the western side. The carbon ratios for coal do not reverse their order, to any great extent if at all, after passing the center of the basin, as does the gas, but continue to decrease west of the basin.

In the Elk-Poca field, Kanawha County, West Virginia, iso-Thv lines on Oriskany gas show a progressive decrease in valûe to the north and west. This indicates that oil will not be encountered in these directions in this field.

It has long been noted that wells drilled in a section along the Ohio River between Huntington and Point Pleasant were nearly void of commercial gas and oil. The carbon ratios for coals in this area vary from 60–45 or well within the carbon-ratio limits for commercial gas or oil. From the data available the Thv or per cent carbon decreases rapidly to that for nearly pure methane as this area is approached. It appears that isometric Thv (iso-carbon) lines for gas may furnish a much better criterion than carbon ratios for coal, in fixing the outer limits of commercial oil and gas in the Appalachian region.

ACKNOWLEDGMENT

In an investigation of this nature the aid and coöperation of individuals and companies are necessary. The writers are pleased to acknowledge the whole-hearted coöperation of hundreds of men in the natural gas industry.

To D. T. Ring and J. R. Lockett, geologists of the Ohio Fuel Gas Company, Wilber Stout, State geologist of Ohio, C. A. Hartnagel, assistant State geologist of New York, J. French Robinson, president of the Peoples Natural Gas Company, and Coleman D. Hunter, geologist for the Kentucky-West Virginia Gas Company, special acknowledgment is due for analyses of gas furnished by them for their respective states; also to J. E. Billingsley, geologist for the Commonwealth Gas Corporation, for data concerning the Oriskany sand and Oriskany gas production in Kanawha County.

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REFUGIO OIL AND GAS FIELD, REFUGIO COUNTY, TEXAS[1]

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ABSTRACT

The Refugio field was discovered in 1919 and has been subjected to sporadic and intermittent development since that time. Subsequent to the discovery of oil in July, 1928, the field has become one of the most important oil fields of the southwestern Gulf Coastal Texas area. Total oil production has been approximately 32 million barrels. Oil and gas are produced from ten separate sand reservoirs and, in addition to these, more than a dozen sands below a depth of 1,600 feet have yielded gas only, but in commercial quantities. Currently the field is producing 4,000 barrels of oil and approximately 45 million cubic feet of gas daily from 156 wells.

Geologically, the field presents an interesting problem because of its recurrent nonconcentric structural uplifts which occurred during the deposition of the different stratigraphic intervals. Oil production has proved that the accumulation is not wholly coincident with the latest structural movement in the area but is retained, in some places, in early folds which have been only partly deformed by later structural movements. In other places, it appears that there has been one or more lateral migrations of the trapped oil and the present producing area is not the original accumulating or structural area. These migrations are shown to be the result of subsequent deformation and tilting of the early structural folding.

INTRODUCTION

In the Corpus Christi area of southwestern Gulf Coastal Texas, gas production in the White Point field, San Patricio County, and oil production in the Kingsville field, Kleberg County, have antedated similar discoveries in the Refugio field, but, by contrast, the latter producing area has proved the most important of the three localities. Strangely enough, there have been few published data available dealing with the structural, stratigraphic, or oil and gas accumulation problems of the Refugio area.

In 1931, R. G. Maxwell[3] read a paper before the San Antonio meeting of the Association in which he dealt with some of the occurrences of water above or between oil and gas in the principal producing zones. In this discussion, Maxwell[4] did not attempt to show the structural conditions of the field, but interpreted the peculiarities of oil and gas accumulation as probably caused partially by sand lensing.

[1] Read before the Association at New Orleans, March 15, 1938. Manuscript received, April 15, 1938.

[2] Chief geologist, Houston Oil Company of Texas.

[3] R. G. Maxwell, "Exceptional Association of Oil and Water in the Producing Zones at Refugio, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931).

[4] R. G. Maxwell, *op. cit.*

In November, 1933, A. E. Getzendaner[5] read a paper before the San Antonio Section of the Association at the Corpus Christi meeting. From this paper, which deals with the structure and stratigraphy of several fields of the Texas Coastal region, the following quotation from the discussion of the structure of the Refugio field has been taken.

> Scanty paleontologic information, combined with comparisons of the ordinarily very poor well logs, indicates that on the "6,400-foot" and shallower sands no abnormalities inconsistent with dome-shaped structure are suggested. The word "suggested" is emphasized. Definite evidence as to the exact nature of the structure is deplorably lacking.[6]

Additional drilling subsequent to the year 1933, coupled with the use of electrical logs, more adequate coring methods and paleontologic information, has assisted materially in deciphering the complex structural conditions which have influenced the accumulations of oil and gas.

It is to be remembered that the Refugio field proved to be the forerunner in the southwestern Gulf Coastal Texas area of a type of deep-seated structure that has led, by subsequent drilling, to the discovery of more than ten oil and gas fields extending more than 100 miles along strike from Jackson County on the northeast to Nueces County on the southwest.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the officers and directors of the Houston Oil Company of Texas, which company has been actively engaged in the production of oil and gas in the area since 1924, for extending permission for the publication of this study; to associate geologists, F. X. Bostick and C. H. Sample, who have assisted in the compilation of paleontologic and geologic information and who have offered helpful comments and criticism; to the Union Producing Company, the D. D. Oil Company, the Local Oil Company, and others for permission to present the electrical logs utilized in the cross sections; to George A. Hill, Jr., and Mrs. Tom O'Connor for assistance in the compilation of the historical record of the locality; to Olin G. Bell and Fred P. Shayes for their assistance and suggestions; and to the many other geologists and individuals who have furnished substantive data and helpful contributions.

An early draft of this paper was presented before group meetings

[5] A. E. Getzendaner, "McFaddin-O'Connor, Greta, Fox, Refugio, White Point, and Saxet Fields, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 4 (April, 1934).

[6] A. E. Getzendaner, *op. cit.*, p. 525.

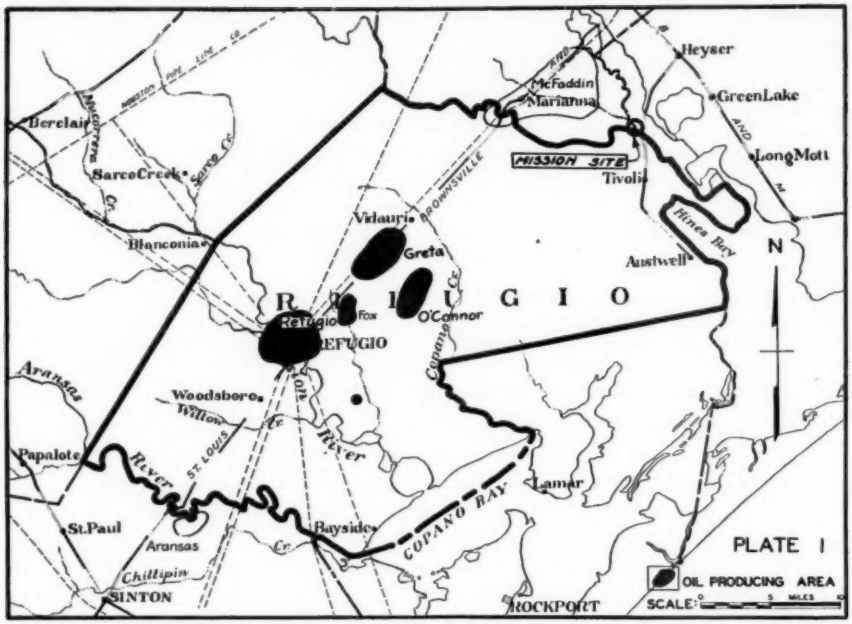

FIG. 1.—Map of Refugio County, Texas, showing location of Refugio, Fox, Greta, and O'Connor productive areas.

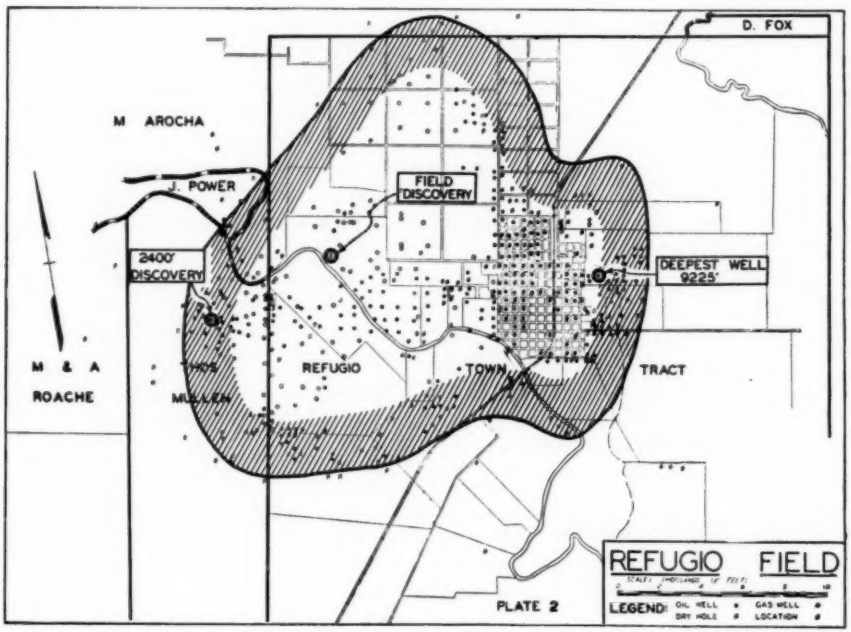

FIG. 2.—Oil and gas productive area of Refugio field. Map indicates also field's deepest well, and discovery wells of field and 2,400-foot sand.

of the Houston Geological Society, the South Texas Geological Society, the South Louisiana Geological Society, and the Dallas Petroleum Geologists during the years 1936 and 1937. The writer is indebted to the discussion by the many geologists in attendance at these meetings. Needless to say, some very pertinent and contributory data resulted from the discussion and were of value in the final compilation of this manuscript.

LOCATION

The Refugio oil and gas field is located in central Refugio County, Texas, on the Gulf Coastal Plain of what has been previously termed "Southwest Texas," being situated approximately midway between Galveston and Brownsville. It is approximately 165 miles southwest of the city of Houston, 125 miles southeast of the city of San Antonio, and 30 miles inland from the Gulf of Mexico.

Figure 1 shows the area of Refugio County and parts of the adjoining counties, and indicates the productive oil and gas fields of the county. The Greta, Fox, and O'Connor fields are located a few miles northeast of the Refugio field, while the Plymouth, Taft, Aransas, and Sinton fields vary from 15 to 25 miles distant toward the southwest. The nearest deep-water ports are at Ingleside, Port Aransas, and Corpus Christi, approximately 35 miles south. Paved roads connect the town of Refugio with all parts of the state and the Missouri Pacific (St. Louis, Brownsville & Mexico) Railroad traverses the townsite part of the field.

The productive area centers in the western part of the Refugio Town Tract and includes parts of the Thomas Mullen, Manuel Arocha, James Power, Isabella O'Brien, and Refugio Town Tract surveys (Fig. 2).

The field derives its name from the town of Refugio, county seat of Refugio County, which townsite area has been proved productive of oil and gas.

HISTORICAL BACKGROUND

The State of Texas celebrates the 100th anniversary of its independence, the town of Refugio, Refugio County, Texas, recalls more than 140 years of history, and the Refugio oil and gas field continues to yield commercial quantities of oil and gas almost 2 decades after its discovery.

When La Salle founded Fort St. Louis on Lavaca Bay, in southern Victoria County, Texas, during the year 1685, it is doubtful that he realized the history-making events that were to ensue. The Spaniards, who had conquered and settled Mexico, resented this intrusion of the

French into the virgin country of the present state of Texas and Captain De Leon was, therefore, sent from Monclova, state of Coahuila, Mexico, to oust the French from Fort St. Louis. Upon his arrival, however, De Leon learned that the depredations of the Indians had already driven the French away and the fort was in ruins.

This French intrusion had its net result in the establishment by De Leon and Father Massenet, during the year 1690, of two missions on the Neches River, in what is now known as southeastern Texas. During the years to follow, many more such missions were built at various locations in the then new Mexican domain, the most historically famous of which are those that are now at the present sites of the city of San Antonio (the Alamo) and at the town of Goliad (Mission La Bahia). All of these missions were managed and directed by friars coming from colleges of the Franciscan Brotherhood, which institutions were, at that time, located in the states of Queretaro and Zacatecas, Mexico. In almost every instance, however, they were supported and protected by a contingent of soldiers.

Because of illicit smuggling during the latter part of the 18th century through the port of Copano on Aransas Bay, the Mexican Government deemed it advisable to establish a mission to control this illegal traffic of contraband goods. And so came into being the last of the Texas Franciscan missions, established in 1793 by Fathers Jose Francisco Mariano Garza and Mariano Velasco at a location at the junction of the Guadalupe and San Antonio rivers. The location of this mission is indicated on Figure 1 as "Mission Site," being approximately 26 miles northeast of the present town of Refugio. After two years, during which time the Texas missions had been secularized by the Mexican Government, it was deemed advisable to remove the mission from its original location to a point more suitable. The earlier location, having been found undesirable because of overflows and fevers, was abandoned and a new mission was therefore established at an Indian village called Aranzazu[7] on what is now known as the Mission River at the present site of the town of Refugio.

Both of the missions, in continuity with church principles, were named "Nuestra Senora del Refugio" (Our Lady of Refuge) and were so named because the original one was begun on that feast day.

Although founded with a motive toward civilization and Christianization of the Carancahua[8] Indians and a sub-tribe of the same na-

[7] Aransas Bay, Aransas River, Aransas County bordering Refugio County on the south, and the towns of Aransas Pass and Port Aransas have derived their names from this original Indian name.

[8] Carancahua Bay and Carancahua Creek have perpetuated the name of this Indian tribe.

tion called the Copanos,[9] the mission history recites a rather tragic ending. When the wars of 1812 began, troops were withdrawn from Texas missions to the interior of Mexico and the savage Comanche Indians descended upon the village, looted the granaries and ravaged the town. Continued abuse by the Comanches necessitated abandonment of the mission in 1824.

Four years later, in 1828, two Irishmen, James Power and James Hewitson, cousins, secured a grant of land from Mexico to colonize with their fellow countrymen. This colonial grant extended from the Coletto Creek on the north to the Aransas River on the south, and westward from the coast to include most of the present Refugio County area. (The original land grant included approximately the area shown on Figures 1 and 7.) A few of the settlers arrived the first year but the main colony came in 1834. The colonists, under the leadership of Power, for Hewitson was never actively associated in planting the colony, made the early Refugio Mission the nucleus of their colony, founded the Refugio Town Tract Survey (Fig. 2) and restored the old mission for use as a parish church.

The Texas Revolution in 1836 completed the ruin of the old mission and a new one now stands at the same locality in Blocks 8 and 11 of the Refugio Townsite area.

The town of Refugio was incorporated in 1834 under the Mexican Government and subsequently operated under charter by President Mirabeau B. Lamar of the Republic of Texas between the years 1842 and 1918. On this latter date, a new charter was adopted.

DISCOVERY AND HISTORY

The first development in the Refugio field was begun in the early spring of 1919 by the Texas Gulf Oil and Gas Association, a stock company organized for the purpose of prospecting for oil and gas in Refugio County. This company located and commenced the drilling of their Bessie Beryl or Heard No. 1 (Fig. 2) on the north bank of the Mission River about 2 miles west and upstream from the town of Refugio, in February, 1919.

Lack of sufficient funds prevented the prosecution of the drilling of the well in a proper manner, but, during the fall of 1919, the well was finally completed as a commercial gas well at a depth of 1,902 feet. The open-flow volume of this well was estimated to be approximately 35 million cubic feet of gas per day.

[9] Copano Bay, Copano Creek, and the town of Copano have retained their original Indian names.

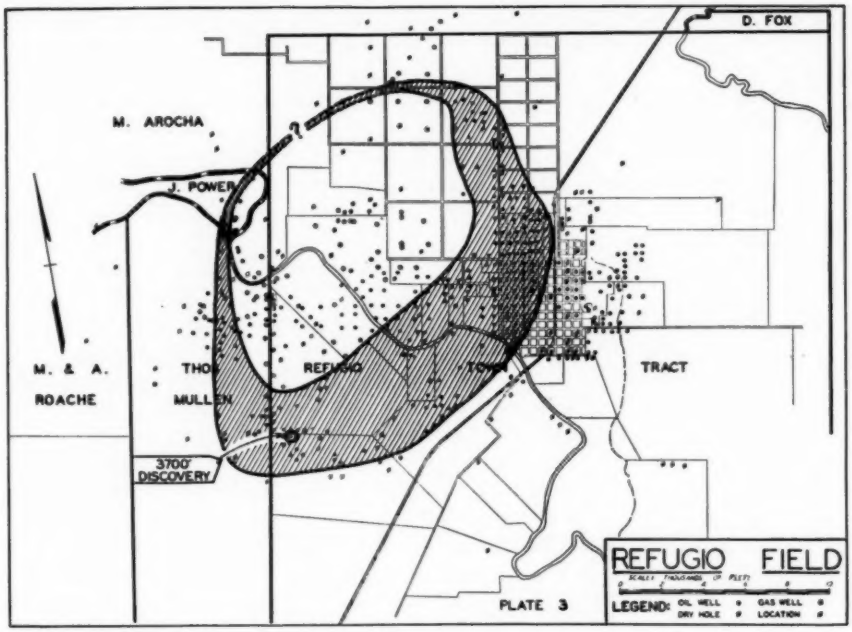

FIG. 3.—Oil productive area of 3,700-foot sand. Map indicates also location of discovery well of that sand.

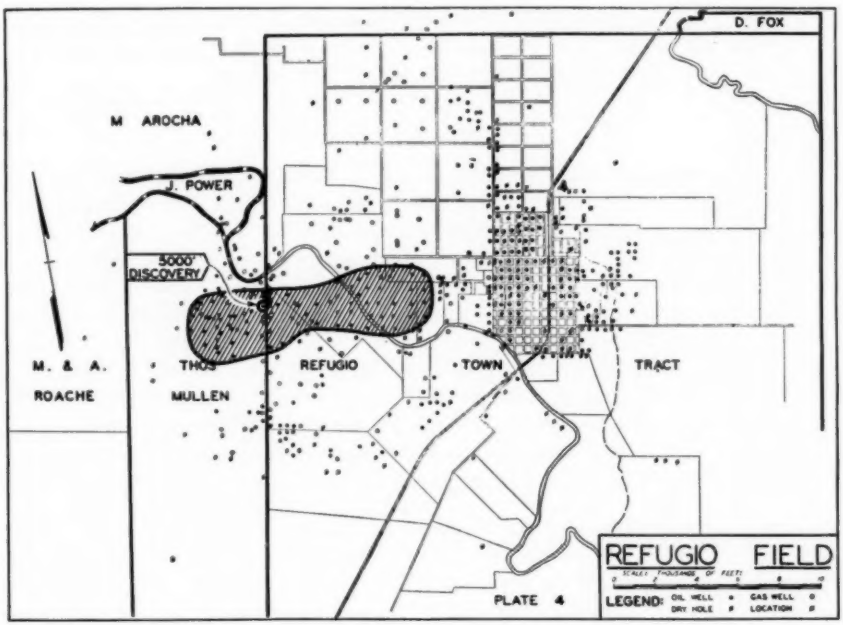

FIG. 4.—Oil productive area of 5,000-foot sand. Location of discovery well of this horizon is shown.

At the time of completion, there was no market for the gas from this well and it remained closed in for several months. In the spring of 1920, a pipe-line connection was made from this well to drilling wells on the south side of the river and it was noted that the Beryl No. 1 made some salt water when gas was withdrawn from the well. The flow of salt water increased until it was found necessary by the State authorities to plug the well with mud-laden fluid, which was done in July, 1923.

In January, 1921, and shortly after completion of the Bessie Beryl No. 1, the Pratt-Hewitt Oil Corporation commenced operations on the Rooke property southwest of the discovery well. This company's first well, the Rooke No. 1, blew out from a depth of 2,220 feet and blew wild for several days. However, it choked itself off, sanded up, and the hole was plugged and abandoned. The second well by the Pratt-Hewitt Oil Corporation, the Rooke No. 2, was the discovery well of the field in the 2,400-foot gas sand (Fig. 2) since it was completed at that depth as a commercial gas well in the fall of 1921.

It is considered impractical, within the scope of this paper, to present a detailed history of the Refugio field since 1921. Development of the field was slow during the years 1922, 1923, and 1924. The year 1925, however, marked the beginning of active development of the area. Many gas wells were completed during the years 1925, 1926, and 1927 and two gas lines were laid from the field, those of the Houston Pipe Line Company and the Houston Gulf Gas Company, the latter now being owned by the United Gas Corporation.

The field has proved, since discovery, more than a dozen separate gas sands and the field's deepest well (Fig. 2) is the Union Producing Company's O'Brien well No. 12, which penetrated a portion of the Vicksburg (*Textularia warreni* zone) shale at its total depth of 9,225 feet. The area outlined by shading on Figure 2 includes the whole of the oil and gas productive area of the Refugio field as of January, 1938, a total of approximately 8,200 acres.

The year 1928 marked the beginning of the extensive development of the area brought about by the discovery of oil in the 3,700-foot sand by the Texas Gas Company in the Clint Heard well No. 1 (Fig. 3). This well was completed, July 4, 1928, as a 400-barrel oil well from sand at 3,681–3,702 feet. Development of the 3,700-foot sand was progressive until the productive area has extended to its present limits of about 2,750 acres (Fig. 3).

Other productive oil and gas sands were discovered by deeper drilling on the structure, the discovery wells of the respective sands being as follows.

3,900-foot oil sand: Houston Oil Company of Texas, Rooke No. 29, completed April 10, 1937, total depth 3,883 feet, initial production 150 barrels of oil per day

5,000-foot oil sand: Houston Oil Company of Texas, Rooke No. 11, completed May 27, 1934, total depth 4,937 feet, initial production 720 barrels. Figure 4 indicates this discovery well and the oil productive area of this 5,000-foot sand which totals approximately 750 acres

5,400-foot sand: Mission Drilling Company, J. J. O'Brien No. 1, completed September 26, 1929, total depth 5,527 feet, initial production 225 barrels of oil per day

5,700-foot sand: Union Producing Company, Powers No. 4, completed July 20, 1930, total depth 5,710 feet, initial production gas and high-gravity oil

6,000-foot sand: Union Producing Company, Lambert No. 8, completed November 2, 1934, total depth 6,095 feet, initial production 200 barrels of oil per day on choke

6,200-foot sand: Houston Oil Company of Texas, Rooke No. 32, completed June 19, 1937, total depth 6,204 feet, initial production 250 barrels of oil per day through ½-inch choke. This sand is the stratigraphic equivalent in the western productive area of the 6,400-foot sand of the townsite (eastern) area

6,400-foot sand: Union Producing Company, Rose Lambert No. 1-A, completed April 4, 1930, total depth 6,465 feet, initial production 120 barrels of oil per day

6,500-foot sand: Republic Gas Company, Scott No. 1, completed November 27, 1937, total depth 6,550 feet, initial production 95 barrels of high-gravity oil per day through ¾-inch choke

6,800-foot sand: Pearson *et al.*, Ryals No. B-1, completed October 27, 1937, total depth 6,797 feet, initial production 110 barrels of high-gravity oil through ½-inch choke.

7,100-foot sand: Union Producing Company, O'Brien No. 12, completed August 25, 1937, total depth 7,114 feet, initial production 128 barrels of high-gravity oil per day through ½-inch choke.

The discovery wells of the 5,400-, 5,700-, 6,000-, 6,200-, 6,400-, 6,500-, 6,800-, and 7,100-foot sands are shown in Figure 5. The combined oil and gas productive area of these sands comprises approximately 1,700 acres. These sands have been grouped as a unit because of their structural relationship which is more fully explained in the following paragraphs.

PHYSIOGRAPHY

Within the environs of the Refugio area there is little of physiographic interest. The normal outcrop of the Lissie sand produces an almost featureless, very gently rolling, prairie land or plain, which slopes coastward at the rate of a few feet per mile. In the inter-stream areas this prairie is best developed. In the western part of the field, Blanco and Medio creeks, normally intermittent streams, join to form the headwater of the Mission River which, in turn, flows southeastward across the central part of the producing area. Locally adjacent to these streams erosion has developed a limited flood plain and, within the area of the field, the Mission River has developed small natural levees. Elevations vary from 25 feet above sea-level in the flood plain to an altitude of approximately 60 feet on the upland terraces or prairies.

There is some evidence, physiographically, to support the post-Beaumont uplift suggested by the surface geology. These evidences are: first, joining of the streams on the upstream side of the structure

and the development of subsequent drainage; second, Lake Butee and other minor oxbow lakes, remnants of the consequent drainage pattern, are located in the northern end of the Thomas Mullen Grant on the northwestern and upstream side of the field; and third, apparent local entrenchment of the meanders of the Mission River only throughout the area that has been affected by the recent uplift.

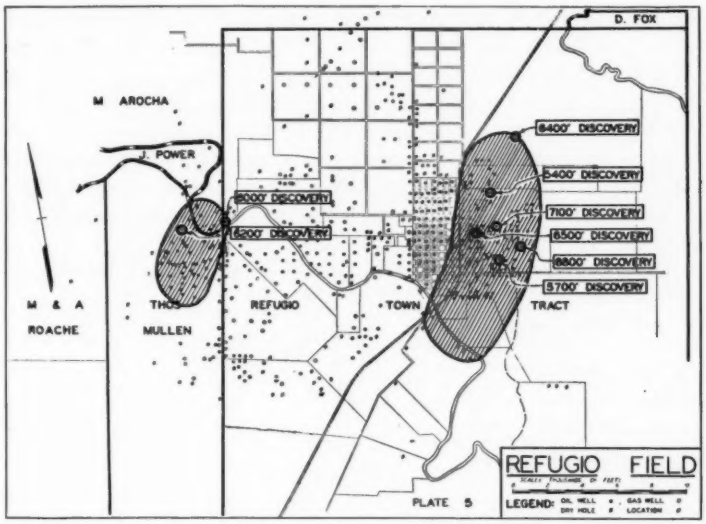

FIG. 5.—Oil and gas productive areas and discovery wells of 5,400- 5,700-, 6,000-, 6,200-, 6,400-, 6,500-, 6,800-, and 7,100-foot sands.

The area is sparsely wooded with live oaks and other typical southwest Texas brush including huisache, mesquite, and chaparral, and, as a whole, is unsuitable as farm land. Individual property ownership, in most cases, is large and cattle raising has been practiced for more than 100 years by the local ranchers and their predecessors. The approximate mean annual rainfall and temperature are 25 inches and 71° F., respectively, as a consequence of which the territory is subjected to normal semi-arid geological processes.

STRATIGRAPHY

Surface.—The surface exposures in the Refugio field are tentatively classed as being Lissie in age and comprise loose deposits of light tan to reddish sands and sandy clays. Flanking the areal extent

of the Lissie outcrop, except on the northwest, are exposures of the black waxy land resulting from the weathering of the gypsiferous clays of the Beaumont. These beds have been more accurately described under the paragraph of this paper dealing with the surface geology of the locality.

Subsurface.—The oldest formation penetrated by the deepest wells has been the *Textularia warreni* shale zone of the Vicksburg formation, Oligocene in age. Within recent years, a complete revision of the stratigraphy has been made. This has been made possible by the additional drilling in the whole of the South Texas area; by the closer correlation between wells by reason of accurate coring, sampling, and electrical log determinations; and by closer paleontologic correlations between the outcrops and the subsurface beds. In 1931, Maxwell[10] stated that 800 feet of the upper Jackson formation of Eocene age had been drilled in the Refugio field. This former Eocene zone is now classed as Vicksburg of Oligocene age.

A fairly complete stratigraphic column of the Refugio field is presented in Table I.

TABLE I

STRATIGRAPHIC COLUMN, REFUGIO FIELD, TEXAS

	Formation	*Thickness in Feet*
PLEISTOCENE	Beaumont clay	Absent
	Lissie sand, Goliad formation } Undifferentiated	1,300
PLIOCENE	Lagarto clays	1,100
MIOCENE	Oakville sands	600
MIOCENE ? OLIGOCENE	Catahoula	700
OLIGOCENE	Marine zone (*Discorbis* shale and *Heterostegina* sand)	650
	Frio?	2,000
	Vicksburg { Upper Sand zone	1,800
	Vicksburg { Lower Shale zone	1,100 Plus
EOCENE	Fayette or Upper Jackson	Not yet penetrated

An idealized type well log of the Refugio field is presented in Figure 6. This log is a compilation from several wells, since local variations in interval and vital changes in stratigraphy, by necessity, will not permit the presentation of one log suitable for all areas of the field. This section to a depth of 5,000 feet, as shown, is comparable with the

[10] R. G. Maxwell, *op. cit.*, p. 954.

logs of wells drilled on the crest of the 3,900-foot structure and from a depth of 5,000 feet to 9,225 feet approximates the log of a well drilled in the eastern or townsite part of the field. An attempt has been made to zone the outstanding shale and sand intervals. These intervals and their respective correlations as between Figure 6 and Table I are described as follows.

Depth in Feet	*Age*	*Description*
0 to 1,300	LISSIE-GOLIAD (Undifferentiated)	Alternating sands and bright colored shales; base of this zone marks base of fresh-water sands
1,300 to 2,400	LAGARTO	Shales with thin lenses of sand carrying gas. Between 1,500 and 2,400 feet, more than 15 lenticular sands were productive of gas on various parts of structure
2,400 to 3,025	OAKVILLE	Sands with alternating beds of shale, sands predominating. Top of this zone is 2,400-foot gas sand and one of outstanding subsurface correlating points (utilized by writer in this study). Other sands in this zone produce gas
3,025 to 3,725	CATAHOULA (First occurrence of volcanic ash)	On crest of structure this zone is defined as shale from 3,025 to 3,600 feet and sand lenses from 3,600 feet to 3,725 feet. In eastern part of field this zone becomes more sandy and is described more fully in dealing with problem of 3,700-foot oil production. This interval includes several productive lenticular gas sands and prolific 3,700-foot oil sand
3,725 to 3,900	MARINE ZONE (*Discorbis* shale)	Top of this shale interval is top of the *Discorbis* zone characterized by *Discorbis* sp. microscopic fossils
3,900 to 4,350	MARINE ZONE (*Heterostegina* sand)	Top of this sand interval is one of important subsurface markers of field (utilized by writer in study of subsurface structure) and is characterized by *Heterostegina* sp. microscopic fossils. Although this sand zone is prolific oil sand of Greta and other fields near by, it has yielded oil or gas in only one well on Refugio structure
4,350 to 6,350	FRIO?	This section, predominantly shale, includes also 5,000-foot oil and gas sand which is excellent subsurface datum, 5,400-foot oil and gas sand, 5,700-foot oil and gas sand, 6,000-foot oil and gas sand, and 6,100-foot oil and gas sand
6,350 to 8,150	VICKSBURG Upper Sand zone	This zone comprises alternating sands with thin lenses of shale—sands predominating. Top of this section is 6,400-foot oil sand of townsite area and 6,200-foot oil sand of Thomas Mullen Grant area; is excellent subsurface datum; and used by writer in this paper. This sand section includes also newly discovered 6,500-foot, 6,800-foot, and 7,100-foot oil and gas sands
8,150 to 9,225	VICKSBURG Lower Shale zone	This thick section of marine, dark colored shales is characterized in upper 400 feet by thin lenses of hard sand and by first occurrence of *Textularia warreni*, typical Vicksburg microscopic fossil

SURFACE GEOLOGY AND STRUCTURE

Credit for the discovery of the Refugio field can be partially attributed to an interpretation of surface geology although the direct

relationship of the surface geology to the structure was probably only imperfectly known at the time.

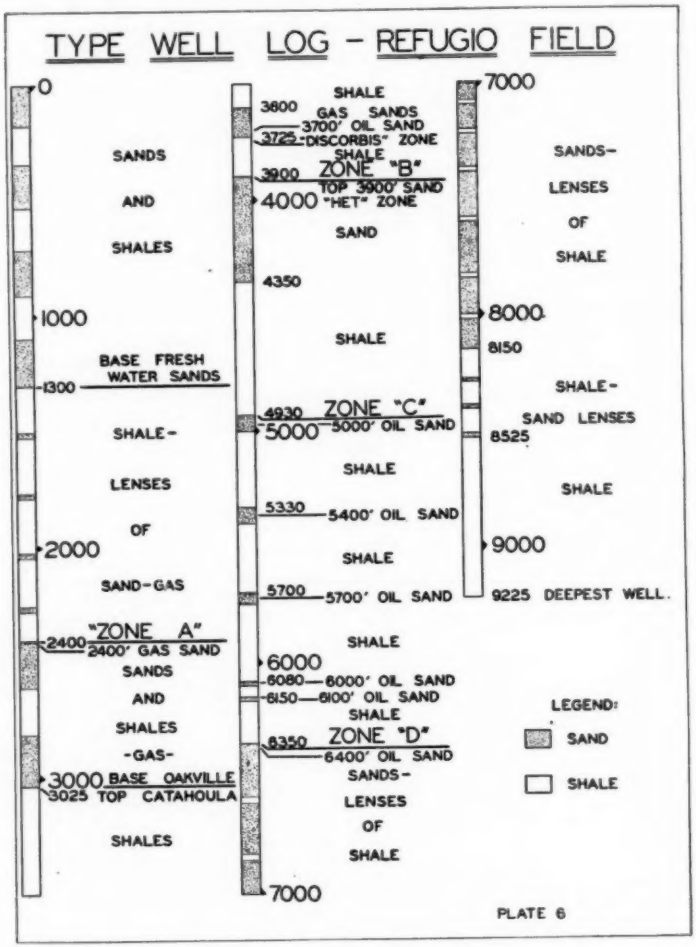

FIG. 6.—Type well log of Refugio field, Refugio County, Texas.

Figure 7 outlines the areal surface geology of the Refugio area. On this map the Lissie-Beaumont contact is marked, the partial extent of the Beaumont clay and Lissie sand outcrops are shown, and the approximate respective field outlines are indicated.

The discovery well, the Bessie Beryl No. 1, was so located because of an outcrop of hard calcareous sandstone in the Mission River near by, coupled with an exposure of loose white sand in the local area. This calcareous sandstone probably represents a phase of the lower Lissie sands since it is overlain by a heavy deposit of sandy material and, on the basis of subsurface interpretations to be presented later, appears to occupy the approximate crest of the most recent structural movement. A probable contributing factor for the location of the discovery

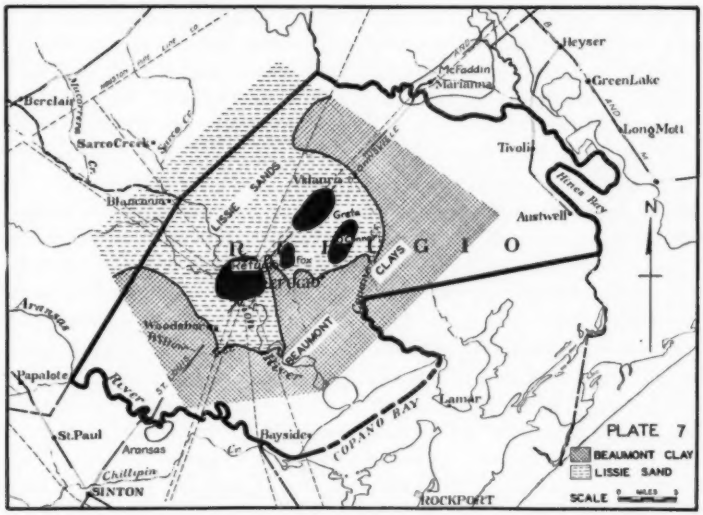

FIG. 7.—Surface geology of Refugio field area.

well was the presence of gas, both sweet and sour, in shallow water wells on the Rooke Ranch on the south. These water wells, of varying depths, produce fresh water, some of which are highly charged with hydrogen sulphide gas.

On the basis of reconnaissance surface geological work on the contact of the Lissie sand-Beaumont clay formations, the surface beds of the Refugio field are believed to be Lissie in age. The productive area of the field is located on an anticlinal nose exhibited by a re-entrant of the Lissie sands southeastward approximately 12 miles into the area of what should be the normal outcrop of the Beaumont clay and evidences upward movement and erosion as late as post-Beaumont. The normal contact (Fig. 7) should be at the approximate Bee-

Refugio and Goliad-Refugio county lines north and northwest and in the normal structurally undisturbed area west of the Refugio field, and east of the Greta field the contact can be so found and mapped.

It is apparent from a study of the surface reconnaissance geological work that the anticlinal nose exhibited on the Lissie-Beaumont contact is large and includes, also, the area of the Greta, Fox, and O'Connor fields. A minor synclinal area between the Refugio field and the Fox and other fields on the northeast is the interpretation on the basis of Beaumont clay outcrops between the two productive spots. This syncline is supported by a study of the subsurface data.

The Beaumont clay formation in this area consists of gray and red calcareous, gypsiferous clays which weather to rich black, waxy, tillable farm land. On the other hand, the Lissie formation consists of tan to reddish sands and sandy clays which weather to light tan sandy soil and in general, except for certain crops, is unsuitable to farming.

The Lissie-Beaumont contact is most positively and quickly identified on the basis of ecology. The Beaumont vegetation is ordinarily dense and consists of huisache, mesquite, and other hardy plants; the area of the Lissie outcrop, by contrast, is generally more open, comprising a luxuriant growth of live oak trees or live oak shrubs. In his latter respect, it is dissimilar to the Beaumont clay since the oaks do not flourish on the waxy clay soil. A marked dissimilarity is also noted in the grasses and other small plants of the two formations. In some places, peculiar types of cacti are known only on the Lissie beds and do not survive on the Beaumont clays.

SUBSURFACE GEOLOGY AND STRUCTURE

This study of the subsurface geology and structure of the Refugio field has presented many difficult questions but has afforded, by the analysis here presented, a method by which many of the tricky structural problems of south Texas may be solved. Lacking definite evidences of correlation from electrical logs and the assistance of paleontologic determinations, most of the previous explanations of oil and gas accumulation isolated from the interpolated structure, on folds of this type, have been made under the supposition of lenticular sands. A comparison of Figures 2, 3, 4, and 5, which maps outline the oil productive areas of the respective oil and gas sands, immediately suggests the non-conformity of accumulation to structure and indicates to the subsurface geologist the possibility that porosity of the reservoir beds might be the plausible explanation for the eccentricities of such accumulation. This review of the geology of the field has shown that lenticularity of sands has affected or influenced oil accumulation

only in the 3,700-foot horizon. In all other cases, oil production is controlled by the retention of the oil either in the earliest and only slightly deformed structure or in the dome-type fold resultant from subsequent upward movement of the reservoir bed.

During 1935 and 1936, electrical logs came into common use in the Texas Gulf Coast. Unfortunately, most of the boom development of the Refugio field during the years 1929, 1930, and 1931 had occurred prior to the advent of electrical logging. As a consequence, and because of the absence of definite paleontologic marker horizons throughout the whole of the stratigraphic column, all previous correlations were only so good as personal interpretations of the very erratic drillers' logs would permit.

After close examination of a few electrical logs of widely spaced wells drilled in the Refugio field during 1935 and 1936, the writer found that definite correlations were possible from sand to sand throughout the whole of the field and that, unless affected by structural uplift, continuity of uniform deposition was the rule rather than the exception. Electrical logs are now available on approximately seventy wells in the field, but as yet are restricted to those parts of the productive area that have had the most recent development. The basis of this structural study has been the correlation of sand and shale intervals as interpreted on the electrical logs, but the study has been extended to the whole of the field by the use of drillers' logs. In order to simplify an understanding thereof, the following general assumptions have been made and are used throughout this paper.

1. Under normal geological conditions, constant and uniform horizontal and vertical deposition of sediments prevails in any very restricted area, such as that now occupied by the Refugio field.

2. The date of a structural uplift may be determined and connected with the sedimentary interval affected.

3. Structural uplifts are reflected in the stratigraphic column by a stratigraphic hiatus, that is, the uplifted area during any sedimentary geologic period is evidenced by missing beds and a short section.

4. Sand zones or stratigraphic sand units, where the upper or any restricted portion of such zone produces oil or gas, are capable of utilization as correlative horizons. It is assumed that conditions in and adjacent to such restricted reservoir beds have been, in the geologic past, favorable for the generation, preservation, and retention of the oil and gas in the interstitial spaces of the sands. The writer realizes that such sand zones were probably deposited near shore on a slightly tilted plane but has neglected this minor variation of interval in this paper.

In order to show pertinent variations of the intervals in the stratigraphic column in various parts of the Refugio field, a general cross section from west to east has been selected. The alignment of this cross section is shown in Figure 8 and was primarily selected through the respective wells because such wells had been drilled deepest and for the reason that electrical logs were available. No attempt was made in this section to show a structural interpretation of the field. The wells used in Section AA' and their respective key numbers on Figures 8 and 9 are as follows.

Key Number	*Company Well Name and Number*	
1	Hogan *et al.*	Kelly No. 1
2	Houston Oil Company of Texas	Rooke No. 33
3	Houston Oil Company of Texas	Rooke No. 32
4	W. F. Morgan	Lambert No. A-1
5	Union Producing Company	Lambert No. 9
6	Houston Oil Company of Texas	W. J. J. Heard No. 18
7	Houston Oil Company of Texas	W. J. J. Heard No. 19
8	Houston Oil Company of Texas	W. J. J. Heard No. 22
9	Union Producing Company	Shelly No. 9
10	Union Producing Company	Rea No. 4
11	Stone *et al.*	Fox No. 1
12	Houston Oil Company of Texas	Ryals No. 6
13	Union Producing Company	O'Brien No. 12
14	Fred P. Shields *et al.*	Ryals No. 1
15	Pearson *et al.*	Ryals No. C-1

Figure 9 presents a cross section of Section AA' on which the variations in interval are indicated. The important stratigraphic differences are here listed.

1. The interval from sea-level to the top of the 2,400-foot sand (Zone *A*) varies from 2,725 feet in well No. 1 to 2,315 feet in well No. 6 and then thickens eastward to a total of 2,555 feet in well No. 15. This indicates a minimum uplift greater than 400 feet, central under well No. 1, such uplift occurring after the deposition of the 2,400-foot sand. These variations in interval similarly reflect the present structure of the 2,400-foot sand.

2. The interval from the top of the 2,400-foot sand to the top of the 3,900-foot sand (Zone *A* to Zone *B*) differs as between well No. 2 and well No. 15 with measurements of 1,463 feet and 1,646 feet, respectively, and indicates a minimum uplift of approximately 200 feet centered under well No. 2 which occurred after the deposition of the 3,900-foot sand and before the deposition of the 2,400-foot sand.

3. The interval from the top of the 3,900-foot sand to the top of the 5,000-foot sand (Zone *B* to Zone *C*) thins eastward from a maximum of 1,275 feet in well No. 1 to a minimum of 800 feet in well No. 15 on the east side of the field. Off structure wells north, south, and east of well No. 15, and not within the scope of this paper, indicate the

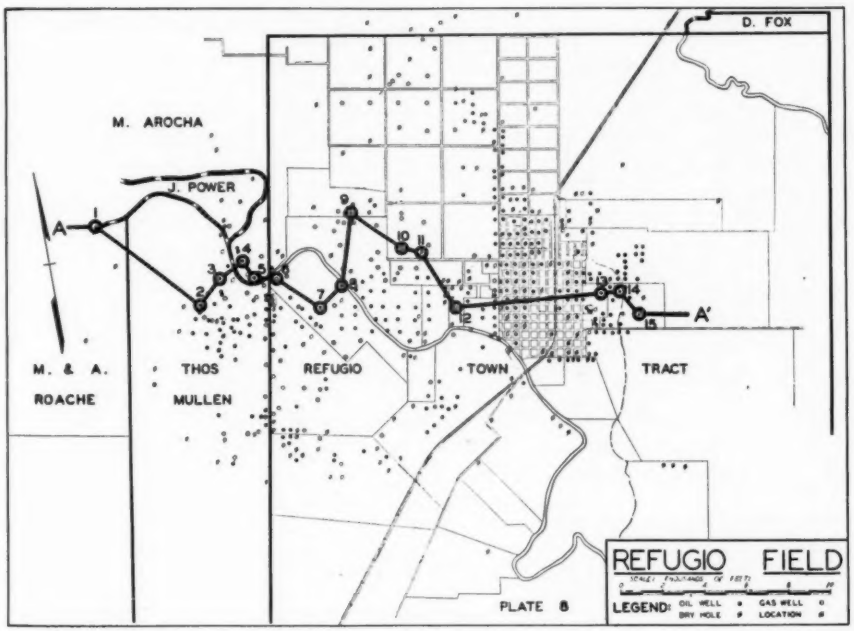

FIG. 8.—Alignment of cross section AA'.

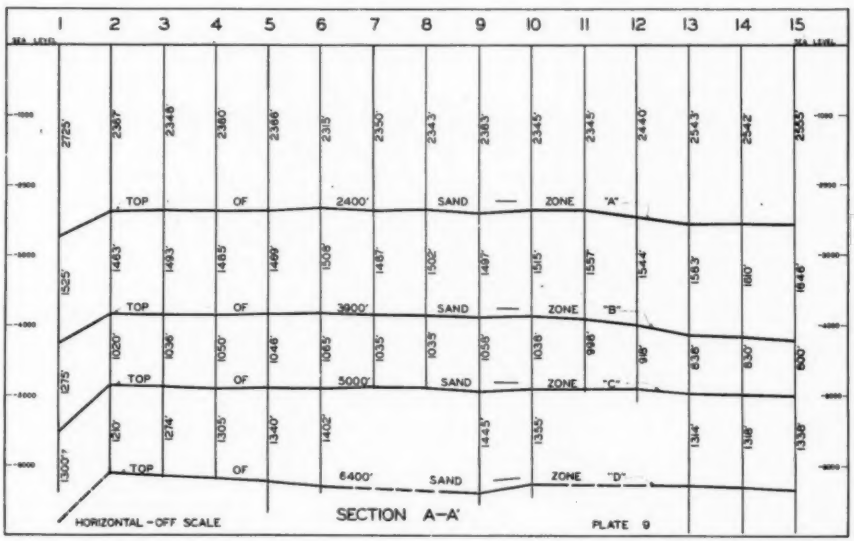
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
SEA LEVEL
TOP OF 2400' SAND ZONE "A"
TOP OF 3900' SAND ZONE "B"
TOP OF 5000' SAND ZONE "C"
TOP OF 6400' SAND ZONE "D"
HORIZONTAL - OFF SCALE
SECTION A-A'
PLATE 9

FIG. 9.—Cross section AA' showing variations in intervals between respective correlative horizons.

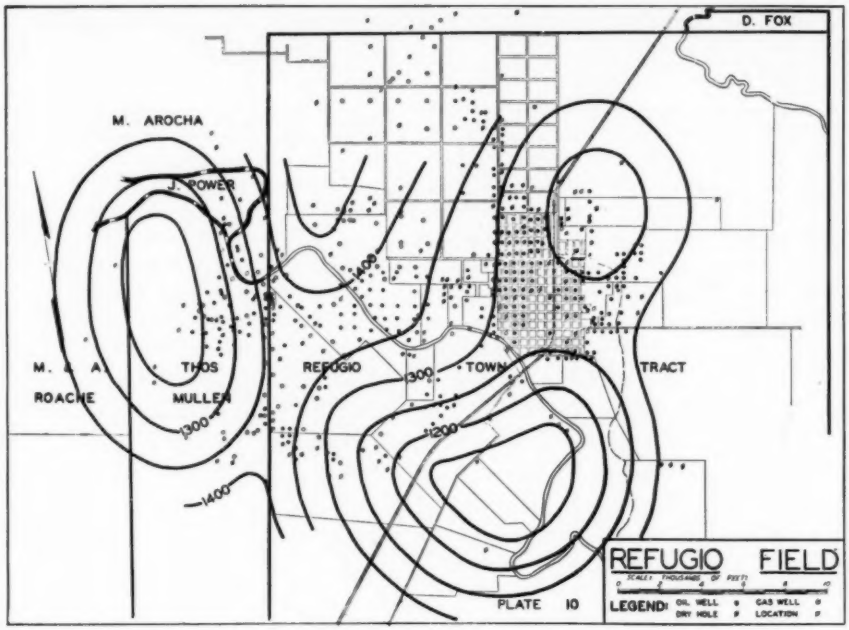

FIG. 10.—Isopach map of interval from top of 5,000-foot sand to top of 6,400-foot sand (Zone *C* to Zone *D*).

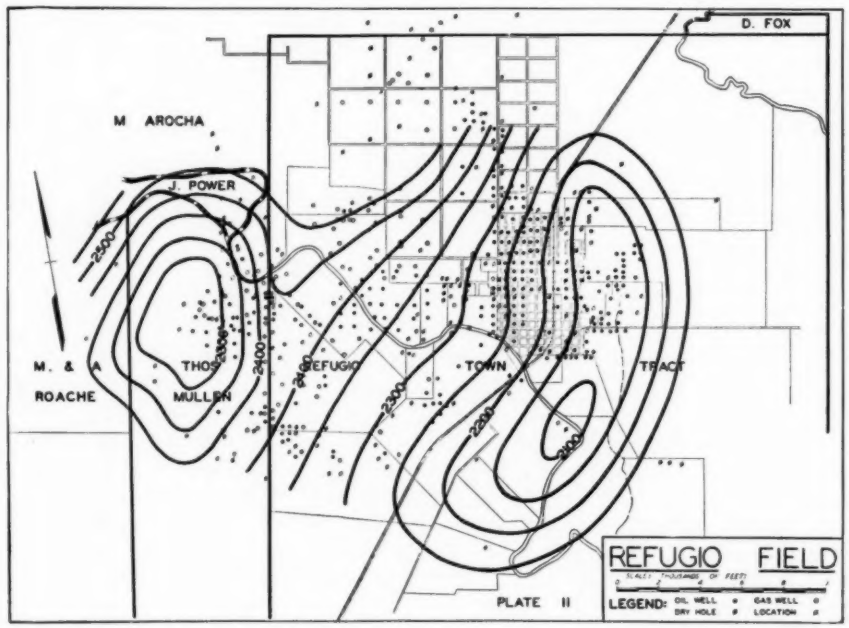

FIG. 11.—Isopach map of interval from top of 3,900-foot sand to top of 6,400-foot sand (Zone *B* to Zone *D*).

increase of this interval, not clearly shown by Section *AA'*. This is interpreted to reflect 475 feet of structural uplift approximately central under well No. 15, which uplift was contemporaneous with the deposition of that interval, occurring post-deposition of the 5,000-foot sand and pre-deposition of the 3,900-foot sand.

4. The interval from the top of the 5,000-foot sand to the top of the 6,400-foot sand (Zone *C* to Zone *D*) fluctuates from a minimum of 1,210 feet in well No. 2 to a maximum of 1,445 feet in well No. 9, and then thins eastward to 1,314 feet in well No. 13. To the writer, these variations in interval reflect structural uplift in the locality of wells 2 and 13, such uplift being concurrent with the deposition of the formations comprising that interval.

These interval interpretations have been extended to all parts of the Refugio field by the use of drillers' logs and other data, and isopach maps of each interval are presented herewith in order that a historical record of the structure of several of the oil-producing zones may be depicted. All maps are of the same horizontal scale and a contour interval of 50 feet has been used throughout.

Figure 10 presents an isopach map on the interval from the top of the 5,000-foot oil sand to the top of the 6,400-foot oil sand (Zone *C* to Zone *D*) and presents a structural picture of the 6,400-foot sand coincident with the close of 5,000-foot sand deposition. So far as can be interpreted from the present relatively shallow drilling data, this represents the first structural movement in the field. This isopach map indicates two structural "highs," one south and southwest of the present townsite area and a second positive element in the western part of the field central in the northern part of the Thomas Mullen Grant. On a restricted study of the townsite area, a part of this uplift is dated as later than the deposition of the 5,400-foot sand and before the deposition of the 5,000-foot sand, since the 5,400-foot, 5,700-foot, and deeper oil horizons are similarly arched, conforming to this interpretation. At the close of 5,000-foot deposition, oil and gas must have been accumulating on these structural "highs" in the 5,400-foot, 5,700-foot, 6,000-foot, 6,400-foot, and other oil sands.

Figure 11 presents an isopach map on the interval from the top of the 3,900-foot sand to the top of the 6,400-foot sand (Zone *B* to Zone *D*). This map represents the resulting structure on the 6,400-foot and associated sands by reason of the two uplifts, one occurring immediately following the deposition of the 6,400-foot sand and the other occurring after the deposition of the 5,000-foot sand. At the close of 3,900-foot deposition, the oil and gas of the 6,400-foot sand in the Thomas Mullen Grant structure must have been more effectively

sealed since the uplift had grown in magnitude. On the other hand, the structure of the townsite area had been deformed by the post-5,000-foot uplift in the townsite area and the oil and gas contained in the early structure to the southwest must have gradually migrated and spread out over the whole of the resulting anticlinal fold.

Figure 12 presents an isopach map on the interval from the top of the 2,400-foot sand to the top of the 6,400-foot sand (Zone *A* to Zone *D*) and, therefore, represents the existing structure on the 6,400-foot and associated sands by reason of the combining effects of the several structural movements. At the close of 2,400-foot deposition, the Thomas Mullen Grant positive element continues to remain structural and, therefore, must have retained its enclosed oil and gas in the 6,400-foot sand. Such is not the fact with respect to the eastern positive area. The townsite area had remained structural while the southwestern end of the former anticlinal fold had been downwarped. By the close of 2,400-foot deposition, therefore, the oil and gas of the 6,400-foot and associated sands must have slowly migrated to the northeastward and were then retained in the structural closure of the townsite area proper.

Figure 13 indicates the present structural interpretation of the 6,400-foot sand and likewise represents an isopach map on the interval from sea-level to the top of the 6,400-foot sand (Zone *D*). The structural anomaly in the Thomas Mullen Grant has remained positive and is now producing oil and gas from the 6,200-foot (stratigraphic equivalent of the 6,400-foot sand of the townsite area) and associated sands. (See productive area outlined in Figure 5.) Post-2,400-foot uplift in the townsite area of the eastern positive element coupled with downwarping of the southwestern end of that feature has effectively sealed the oil and gas in the northern portion of the former anticlinal type fold. Oil and gas are now being produced from wells within the minus 6,300-foot closure in the townsite area (Fig. 5) and wells drilled on the early structural "high" at the southwest have exhibited some short stratigraphic intervals and light showings of oil and gas but have not been productive.

Figure 14 presents an isopach map on the interval from the top of the 3,900-foot sand to the top of the 5,000-foot sand (Zone *B* to Zone *C*) and, therefore, depicts the structural picture of the 5,000-foot sand at the close of 3,900–foot deposition. At that time, a very definite positive anomaly was central in the Refugio townsite area and a minor positive element was established in the western area of the field in the vicinity of the northern part of the Thomas Mullen Grant. It is inferred that, at the close of 3,900-foot deposition, oil and gas was

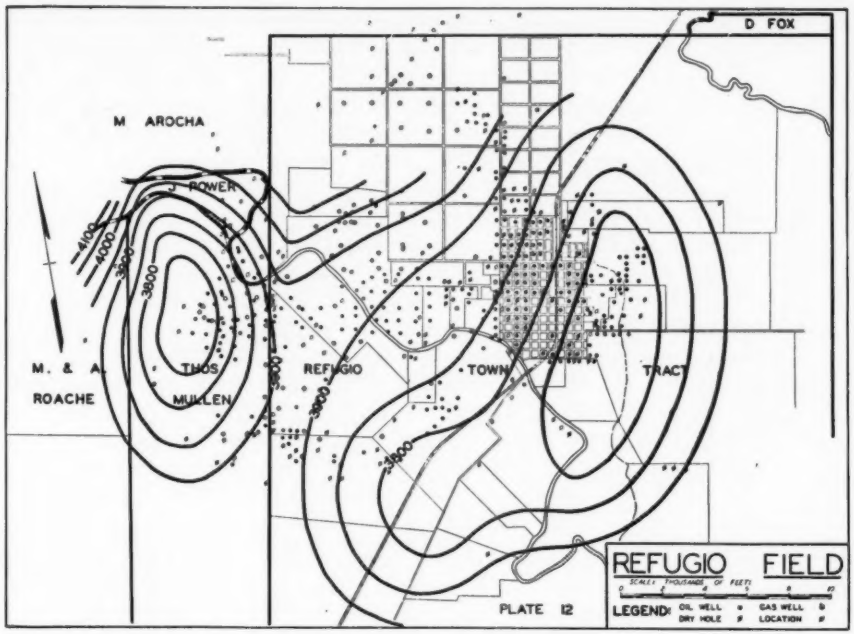

FIG. 12.—Isopach map of interval from top of 2,400-foot sand to top of 6,400-foot sand (Zone *A* to Zone *D*).

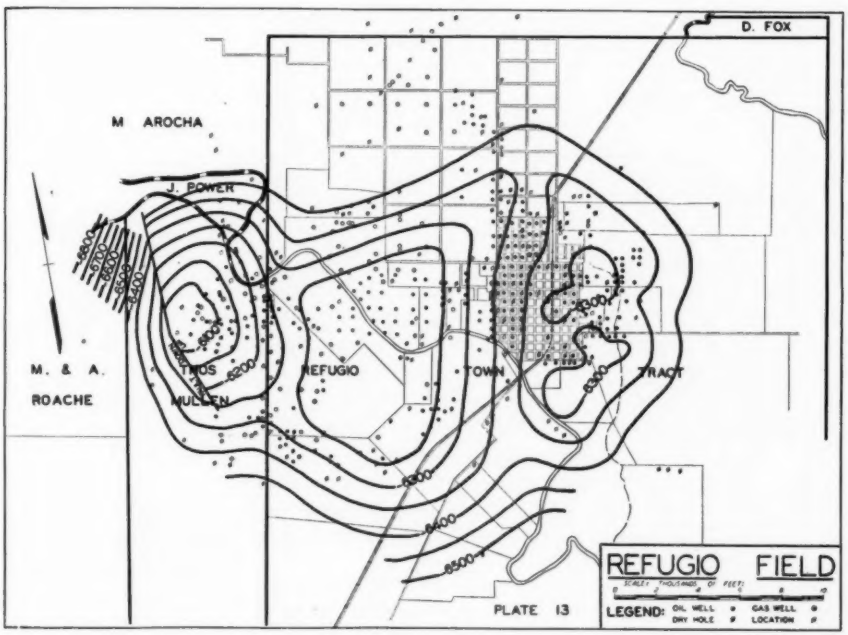

FIG. 13.—Structural contour map of 6,400-foot sand (Zone *D*).

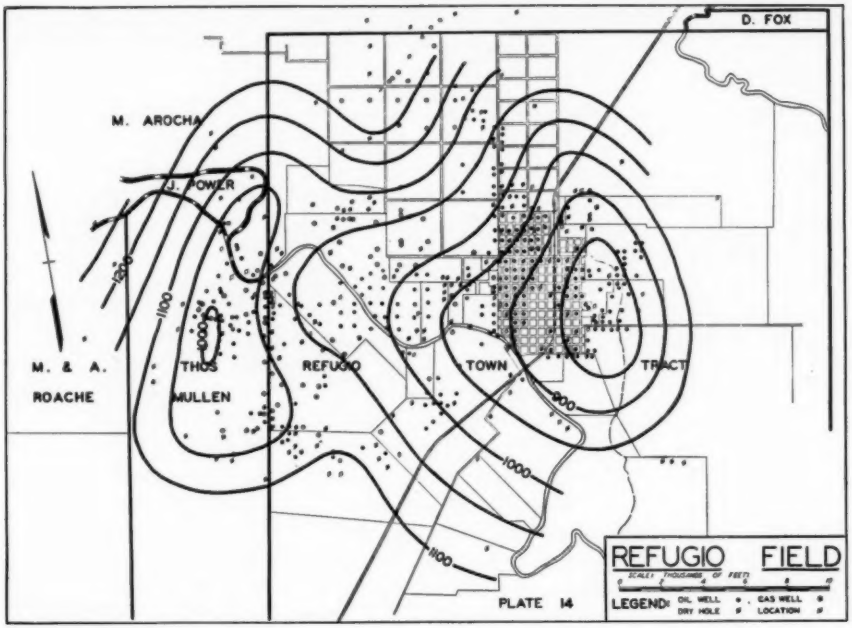

FIG. 14.—Isopach map of interval from top of 3,900-foot sand to top of 5,000-foot sand (Zone *B* to Zone *C*).

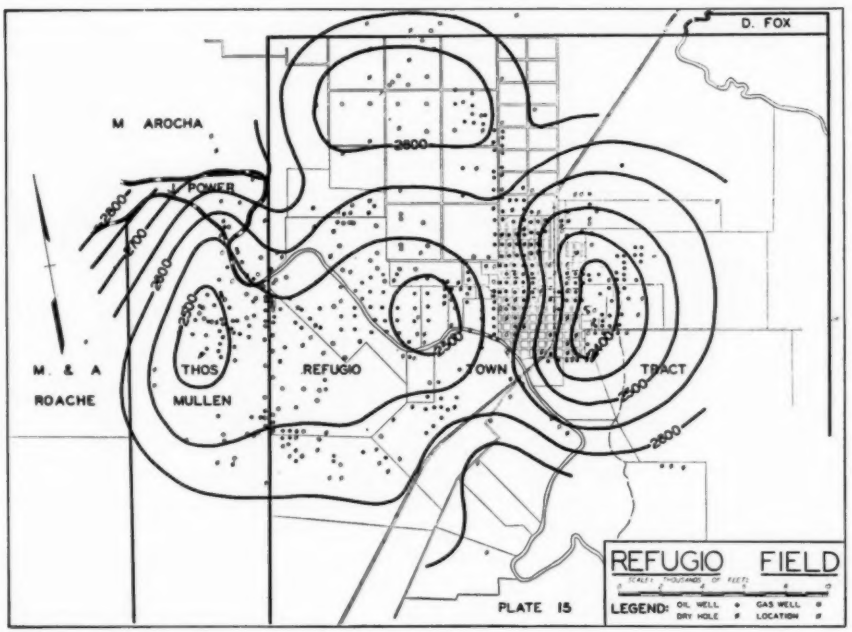

FIG. 15.—Isopach map of interval from top of 2,400-foot sand to top of 5,000-foot sand (Zone *A* to Zone *C*).

definitely accumulating on the eastern or townsite anomaly and probably so accumulating on the minor fold on the west.

Figure 15 presents an isopach map on the interval from the top of the 2,400-foot sand to the top of the 5,000-foot sand (Zone *A* to Zone *C*) and, therefore, represents the structure resulting from the effects of the post-3,900-foot deformation of the earlier uplift. At the close of 2,400-foot deposition there were two positive elements, one very definite feature in the townsite area and a broader less acute structure over the whole of the western part of the field. By a very detailed study of respective isopach intervals of stratigraphic zones between 2,400 feet and 3,900 feet it can be shown that the oil and gas that had originally accumulated in the 5,000-foot sand in the townsite area had migrated to the western part of the field and then returned to the townsite area by the close of 2,400-foot sand deposition. This detailed study of the migration shows the following.

1. Accumulation in townsite area shortly after deposition of the 5,000-foot sand and prior to close of 3,900-foot deposition
2. Migration to a structural "high" in the western part of the field at close of Catahoula
3. Return to townsite area by close of 2,400-foot deposition

Figure 16 presents the structural interpretation of the 5,000-foot sand at the present time and represents an isopach map on the interval from sea-level to the top of the 5,000-foot sand (Zone *C*). Two anomalies are evidenced, one broader feature over the western portion of the field and one in the townsite, although, by this time, the townsite structural area has been tilted downward to the east and the oil and gas of this latter area has been practically lost by migration to the higher structural feature on the west, from which area oil and gas are now being produced (Fig. 4). In the townsite area, a few wells have produced small quantities of gas and some have encountered oil showings in this sand but, as yet, no commercial oil production has been obtained.

Figure 17 presents an isopach map on the interval from the top of the 2,400-foot sand series to the top of the 3,900-foot sand (Zone *A* to Zone *B*) and indicates the existing structure on the 3,900-foot sand at the close of deposition of the 2,400-foot sand. Essentially, this map presents a combination of two structural movements inasmuch as a very close study would show the Catahoula section thinning toward a structural "high" in the western part (Thomas Mullen Grant) of the field and the Oakville sand section thinning eastward toward a positive area centered about the townsite area. The major uplift, however, which is post-*Discorbis* shale in age, occurred in the western and northern parts of the field and has been the controlling factor concern-

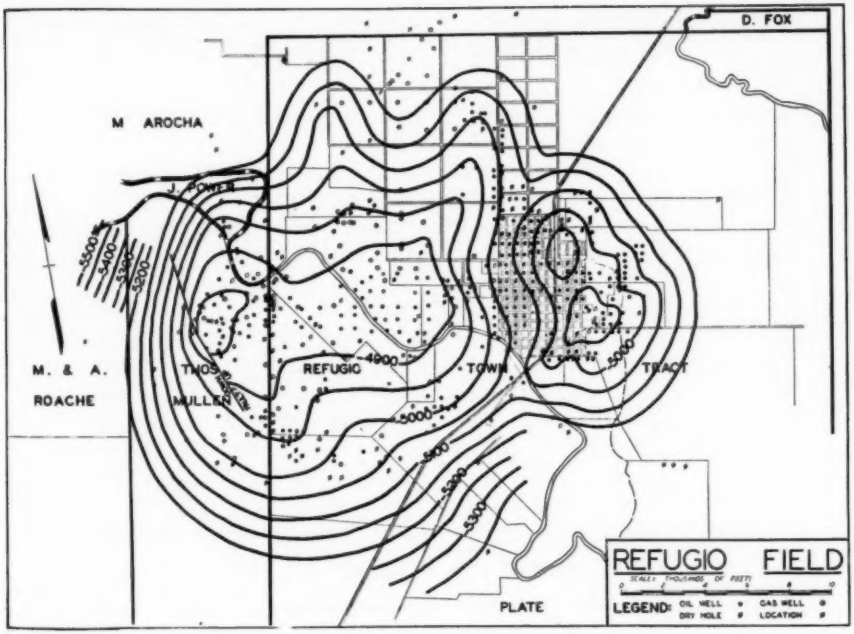

FIG. 16.—Structural contour map of 5,000-foot sand (Zone *C*).

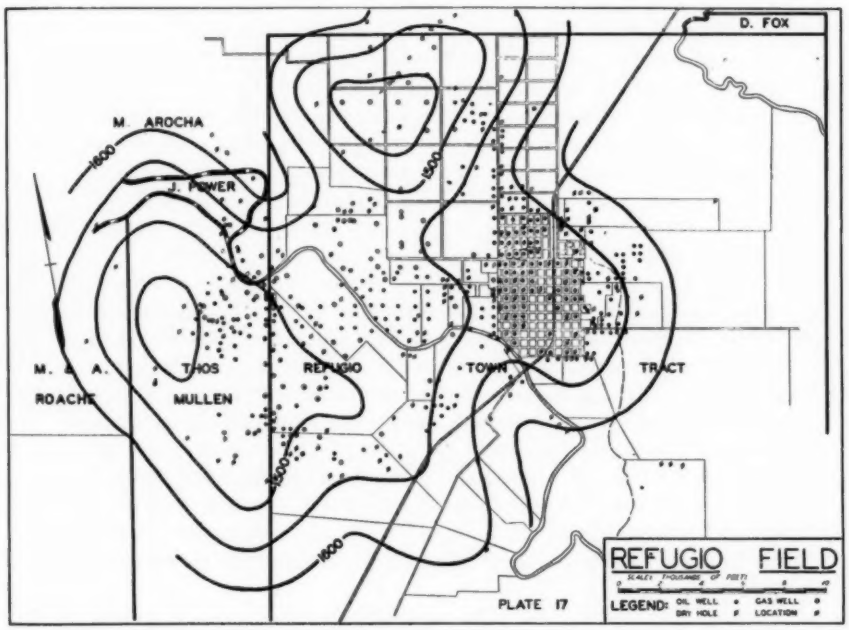

FIG. 17.—Isopach map of interval from top of 2,400-foot sand to top of 3,900-foot sand (Zone *A* to Zone *B*).

ing 3,700-foot oil accumulation. The 3,700-foot sand, rather thick eastward off structure, thins toward the western structural "high" (Fig. 20) and lenses out against the *Discorbis* shale section. At the close of 2,400-foot deposition, oil and gas must have been accumulating in the foreset lenticular 3,700-foot sands flanking the two "highs" suggested by Figure 17.

Figure 18 presents the structural interpretation of the 3,900-foot sand at the present time and, therefore, represents an isopach map on

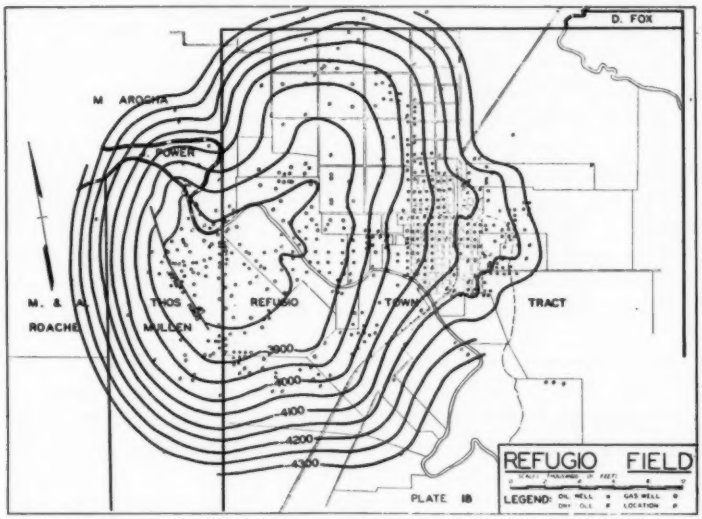

FIG. 18.—Structural contour map of 3,900-foot sand (Zone *B*).

the interval from sea level to the top of the 3,900-foot sand (Zone *B*). The oil and gas, originally accumulated in the 3,700-foot sands, have been retained in approximately the same respective position but have been adjusted by gravity to conform with the sand and structural conditions now existent. The width and position of the 3,700-foot producing area (Fig. 3) are relative to the present dip of the beds and to the previous conditions of deposition. An electrical log cross section of the zone of oil accumulation in the 3,700-foot sand has been prepared to illustrate this controversial point. Figure 19 shows the alignment of the section. The electrical logs of the following wells were used in this study.

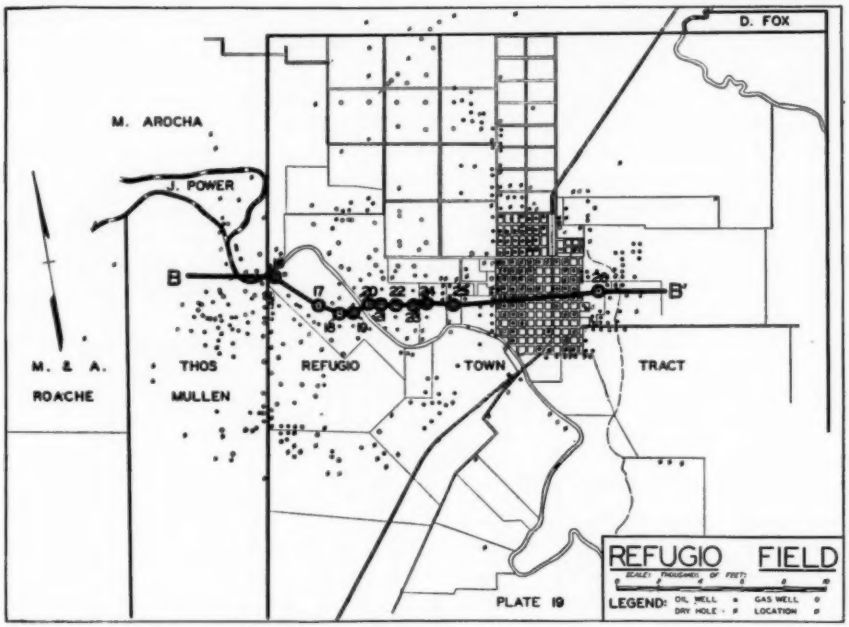

FIG. 19.—Alignment of cross section *BB'*.

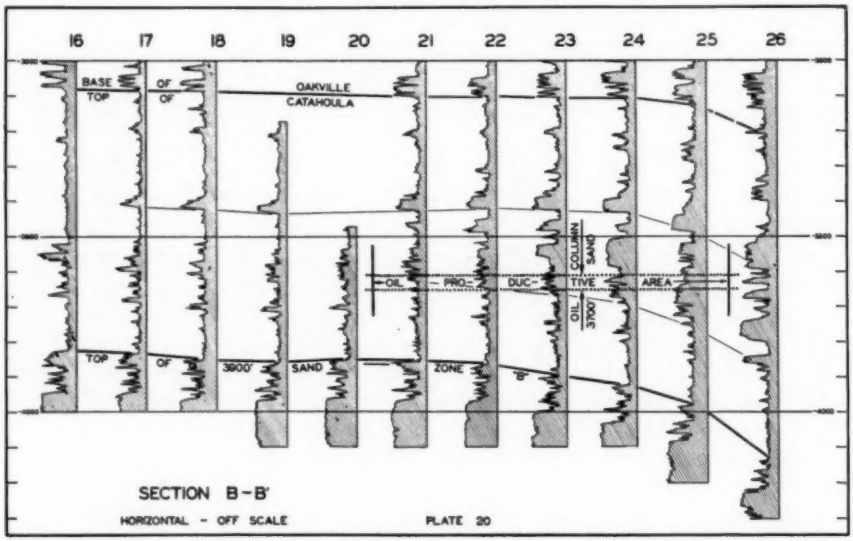

FIG. 20.—Cross section *BB'*, utilizing electrical logs, indicating variations in porosity of 3,700-foot sand and resulting oil productive area.

Key Number	*Company Well Name and Number*	
16	Houston Oil Company of Texas	W. J. J. Heard No. 18
17	Houston Oil Company of Texas	W. J. J. Heard No. 19
18	Houston Oil Company of Texas	W. J. J. Heard No. 20
19	D. D. Oil Company	Heard No. 5
20	D. D. Oil Company	Heard No. 3
21	Union Producing Company	Heard No. 13
22	Union Producing Company	Heard No. 15
23	Union Producing Company	Heard No. 14
24	Local Oil Company	Rea No. 2
25	Houston Oil Company of Texas	Ryals No. 6
26	Union Producing Company	O'Brien No. 12

Unfortunately, all of the development of the 3,700-foot sand in the townsite area was completed during 1929 and 1930, and consequently no electrical logs are available of any of the wells in the principal producing area between key wells 25 and 26. This electrical log section showing porosity only is presented in Figure 20 and by reference thereto the reader may note:

1. The correlation of the base of the Oakville sands or top of the Catahoula shale section
2. The excellent correlation on the top of the 3,900-foot sand (Zone B)
3. Correlations on the base of the 3,400-foot gas sand and the base of the 3,700-foot sand section are shown by light lines
4. The oil column of the 3,700-foot sand is shown as between −3,610 feet and −3,650 feet subsea
5. The actual width of the developed productive area of the 3,700-foot sand is shown as comprising wells 21–25, inclusive

It is readily noted from this section that the heavy sands of the townsite area lens out westward, lose their respective porosity by reason of interstratified shale,[11] and become nonproductive of oil. Some gas is produced on the western structure from 3,600-foot sands that are the apparent equivalent of the 3,700-foot sands on the east. The latter correlation, however, is far from definite.

Figure 21 presents the generalized structural interpretation of the 2,400-foot sand at the present time and, therefore, illustrates an isopach map on the interval from sea-level to the top of the 2,400-foot sand (Zone *A*). This map indicates the post-2,400-foot uplift which was centered in the western part of the Refugio Town Tract Survey and suggests, by elongation of the structure to the northeast, the uplift which occurred after deposition of the 1,600-foot sand and which was centered about the northern part of the field. Another evidence of post-2,400-foot uplift, and more probably post-Beaumont clay deposition in age, is evidenced by the surface geology (Fig. 7). In support of the post-2,400-foot uplift, gas has been produced from the 2,400-foot, 2,100-foot, 1,900-foot, and other shallow sands over most of the area of the structure here depicted.

[11] R. G. Maxwell, *op. cit.*, p. 956.

In the preceding paragraphs, an effort has been made to visualize and present the historical structural development of the principal oil and gas-producing zones of the field, particularly where that structural development, by recurrent uplift, is thought to have effected oil accumulation and migration. It is readily noticeable that the early structure-making forces were restricted to those localities described as the Townsite area and the Thomas Mullen Grant area,

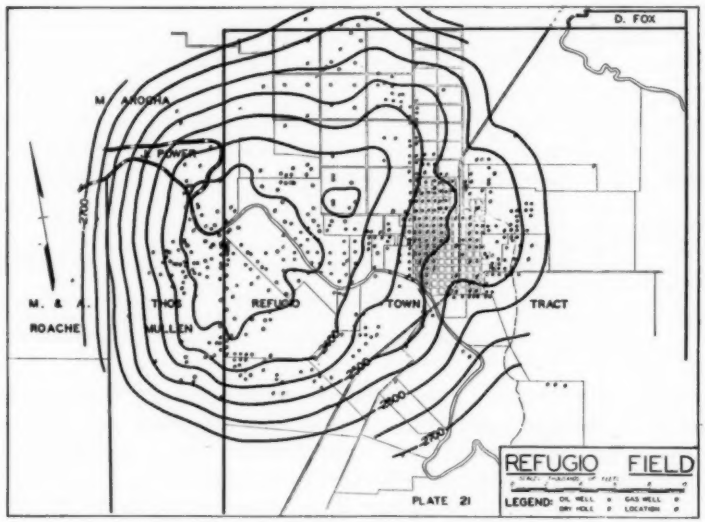

FIG. 21.—Structural contour map of 2,400-foot sand.

on the east and west limits of the present known productive area. The more recent structural movements, however, have been centralized in the Town Tract area between the early structural "highs." Lacking positive evidence to the contrary, the writer suggests that the motivating force for the structural uplift has been salt flowage at great depths. This thought is offered since it would answer the question of recurrent upwarping of the various stratigraphic intervals. A reconstructed cycle of geologic history, in chronological order, would then be: (1) deposition and loading of weight on deep-seated salt beds, such deposition being complete to the point of instability of the underlying salt; (2) flowage of the salt upward, along the lines of least resistance, penetrating and/or arching the overlying sediments, until

equilibrium of deposition and the compressional force on the salt bed were reached; and (3) additional deposition of sediments over the whole area until instability of the salt and sedimentary interval is again obtained, at which time the salt will again flow upward through the weakest channels, until static conditions prevail. Four such approximate geologic cycles are suggested by the isopach maps herewith included, although sedimentation and salt movement may have been contemporaneous.

It is reliably reported that torsion-balance work[12] in the Refugio field area outlines a minimum-gravity anomaly and thereby suggests deeply buried salt. While not indicative of salt, it has been shown that electrical-resistance measurements[13] of water from wells producing from the Lissie sands will define an anomaly coincident with the Refugio structure. These variations in electrical resistance measurements are thought to be attributable to localized mineralization of the surface waters.

FAULTING

Positive evidence of faulting is known in only one locality in the Refugio field, indicated on the present structural contour maps of the 3,900-foot, 5,000-foot, and 6,400-foot sands (Figs. 13, 16, and 18), in the locality of the western side of the Thomas Mullen Grant. This normal fault, which dips to the west (east side upthrown) at an angle of 48°, demonstrates progressive movement since deposition of the so-called 6,400-foot sand. Throw of the fault in this sand is in excess of 100 feet, it shows approximately 50 feet of displacement on the 5,000-foot sand, and has been reduced to westward monoclinal dip on the top of the 2,400-foot sand. Suggested deep-seated faulting, affecting the sedimentary intervals below 6,400 feet, may be extrapolated from certain well data in the area west of the Townsite positive element. Getzendaner[14] has previously pointed to the paleontologic evidence supporting this phenomenon. The structural saddle west of the Townsite area and contoured on the structural maps of the 6,400-foot and 5,000-foot sands similarly support this hypothesis. If existent this fault will strike approximately north and dip east. This suggested fault and the known fault on the west are both tensional faults and their historic development can be associated with the whole structure-making influence.

[12] Robert N. Kolm, Atlantic Refining Company, personal communication.

[13] Gage Lund, Standard of Texas, personal communication.

[14] A. E. Getzendaner, *op. cit.*, pp. 526 and 527.

PRODUCTION

From the best available figures, as of January 1, 1938, the production of gas and oil from the Refugio field is as follows.

Gas: in excess of 271 billion cubic feet[15]
Oil: approximately 32 million barrels divided as follows
High-gravity: 11.5 million barrels (above 25° Bé.)
Low-gravity: 20.5 million barrels (below 25° Bé.)

Yearly production figures of high- and low-gravity oil are presented in Table II. It is of interest to note that the 3,700-foot sand, yielding the low-gravity oil, has produced almost twice as much oil, to the present time, as all of the other high-gravity sands combined. The future should effect a possible reversion of this relation since current production and development have been from sands yielding high-gravity oil.

TABLE II

OIL PRODUCTION, REFUGIO FIELD, TEXAS

Year	*Low-Gravity*	*High-Gravity*	*Total*
1928	59,212		59,212
1929	1,986,385	29,719	2,016,104
1930	9,367,058*	1,857,454	11,224,512
1931	4,345,550	4,419,012†	8,764,562
1932	1,792,763	907,647	2,700,410
1933	1,047,188	510,718	1,557,906
1934	695,448	434,587	1,130,035
1935	443,973	726,297	1,170,270
1936	378,161	1,123,681	1,501,842
1937	314,216	1,536,058	1,850,274
Total	20,429,954	11,545,173	31,975,127

* March peak of 1,075,161 barrels during month.
† April peak of 510,244 barrels during month.

On January 1, 1938, the average daily allowable field production of gas and oil was:

Gas: 45 million cubic feet per day from 50 wells
Oil: 4,200 barrels per day from 106 wells

GAS ANALYSES AND OIL GRAVITIES

Representative samples of gas from the gas sands in the Refugio field have shown the following approximate analysis.

[15] This figure does not include gas wastage which, during parts of 1930 and 1931, totaled as much as 200 million cubic feet per day wasted into the air in the production of oil from the deep sands.

	Per Cent
Methane	99.1 to 99.3
Nitrogen	.4 to .5
Carbon dioxide	.2 to .5
Specific gravity	.56
Heat value	1,000 BTU per cubic foot

In some of the so-called "gasoline" wells producing from the deeper sands, the specific gravity of the gas increases to about 0.66, the percentage of methane (CH_4) decreases to approximately 95 per cent and is replaced by ethane (C_2H_6) to a maximum of 4 or 5 per cent. The gasoline content of the gas from the deeper sands varies from approximately 0.3 gallon to approximately 1.3 gallons of gasoline per thousand cubic feet of gas.

Oil produced from sands in the Refugio field has the following gravities.

Sand	*Degrees*
3,700-foot	24
5,000-foot	31–32
5,400-foot	33–62
5,700-foot	36–62
6,000-foot	38
6,400-foot	34–62
6,500-foot, 6,800-foot, 7,100-foot	50–63

A peculiar feature of wells in the townsite area of the Refugio field completed in the 5,400-foot and deeper sands is that wells, shortly after completion, produced water-white oil of about 62° gravity and subsequently, in the course of time, the gravity dropped to approximately 40° and the oil became colored.

Many of the shallow gas sands produced small amounts of a light oil known locally as turpene because of its turpentine odor.

PERTINENT DATA

In order to outline the essential points as to area of production, producing wells, statistics of pipe lines and compressor stations, *et cetera*, Table III is presented herewith.

TABLE III

PERTINENT DATA, REFUGIO FIELD, TEXAS

January 1, 1938

1. Producing area of total field, gas and oil	8,200 acres
2. Producing oil area, 3,700-foot sand	2,750 acres
3. Producing oil area, 5,000-foot sand	750 acres
4. Producing oil and gas area, 5,400-foot and deeper sands (Includes 5,700-foot, 6,000-foot, 6,200-foot, 6,400-foot, 6,500-foot, 6,800-foot, and 7,100-foot sands)	1,700 acres

TABLE III—(continued)

5.	Total production of field, gas (Not inclusive of gas wastage)	271,097,103,000 cubic feet
6.	Total production of field, oil	31,975,127 barrels
7.	Total production of field, low-gravity oil	20,429,954 barrels
8.	Total production of field, high-gravity oil	11,545,173 barrels
9.	Total wells drilled in field	560 wells
10.	Total wells drilled, 3,700-foot sand	245 wells
11.	Total wells drilled, 5,000-foot sand	72 wells
12.	Total wells drilled, 5,400-foot and deeper sands (Includes 5,700-foot, 6,000-foot, 6,200-foot, 6,400-foot, 6,500-foot, 6,800-foot, and 7,100-foot sands)	136 wells
13.	Daily allowable oil production, January 1, 1938	4,002 barrels
14.	Daily allowable gas production, January 1, 1938	45,780,000 cubic feet
15.	Producing oil wells (all sands), January 1, 1938	106 wells
16.	Producing oil wells, 3,700-foot sand, January 1, 1938	19 wells
17.	Producing oil wells, 5,000-foot sand, January 1, 1938	61 wells
18.	Producing oil wells, 5,400-foot and deeper sands, January 1, 1938 (Includes 5,700-foot, 6,000-foot, 6,200-foot, 6,400-foot, 6,500-foot, 6,800-foot, and 7,100-foot sands)	26 wells
19.	Producing gas wells, all sands, January 1, 1938	50 wells
20.	Gas pipe lines serving field	3
	a. United Gas Corporation	
	b. Houston Pipe Line Company	
	c. Utilities Natural Gas Company	
21.	Gas compressor stations in field	2
	a. United Gas Corporation	
	b. Houston Pipe Line Company	
22.	Gasoline absorption plants in field	2
	a. United Gas Corporation, daily capacity, 50 million cubic feet	
	b. Clymore, Incorporated, daily capacity, 30 million cubic feet	
23.	Oil pipe lines serving field	2
	a. Atlantic Pipe Line Company, Harbor Island terminus	
	b. Humble Oil and Refining Company, Ingleside terminus	
24.	Oil refineries in field	1
	a. Refugio Refining Company, daily capacity, 2,000 barrels	

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ORIGIN OF RED SEA DEPRESSION[1]

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ABSTRACT

The various hypotheses current with reference to the origin of the Red Sea depression are reviewed, and it is pointed out that a considerable part of the Red Sea littoral is still geologically unstudied. In particular, no geological information has been available dealing with the Hedjaz coast. This comprises the whole of the northern part of the eastern shore of the Red Sea and the eastern shore of the Gulf of Aqaba. The field data, now collected in that area, confirm the assumption that the Gulf of Aqaba and the Red Sea are separate tectonic units. No field evidence of regional faulting parallel to the Red Sea, on its eastern coast line, has been observed.

The Red Sea is a strip of water, narrow in comparison to its length, which extends from Suez (lat. 30° N. approx.) to Bab el Mandeb (lat. 12° 30′ N. approx.), a distance of approximately, 1,200 miles. Its breadth is greatest in the region of lat. 16° N., where it is 250 miles, but it decreases northward to 130 miles in lat. 27° 45′ N., there dividing into two branches—the Gulf of Suez and the Gulf of Aqaba. The southern extremity of the Red Sea is marked by a constriction, less than 20 miles across, which connects it to the Gulf of Aden.

The mean depth of the Red Sea is less then ⅓ mile, approximately 1,600 feet, but, even with the meager data available, the bottom is known to be very irregular. For example, it is crossed by a very definite shoal (360 feet) in lat. 25° 40′ N. North of this shoal, the maximum depth is 3,840 feet while south of it a depth of 7,200 feet is attained in lat. 22° 7′ N.

Wherever sufficient data are available to enable the submarine contours to be mapped in any detail, the contours are found to be extremely crenulate, and not rectilinear as they generally appear on the standard maps. Small-scale mapping, with its concomitant generalization, causes the deeps of the Red Sea to appear as a belt of narrow, straight-sided troughs, and it is not surprising that this striking feature in world topography should be assumed to be due to the sinking of a strip of the earth's crust between parallel faults whose orientation is identical with that of the existing Arabian and northeast African shore lines.

Suess,[3] quoting Fraas,[4] was the first to bring this suggestion into

[1] Manuscript received, March 9, 1938.

[2] Consulting geologist, The Institution of Petroleum Technologists.

[3] E. Suess, *Das Anlitz der Erde*. Leipzig (1883–1909).

[4] O. Fraas, *Aus dem Orient*. Stuttgart (1867–68).

prominence and to assign to it a fundamental significance in world tectonics. Gregory[5] accepted and amplified the conception of Suess and postulated the existence of a series of connected rift valleys extending from the Jordan valley southward to Lake Nyasa in South Africa by way of the Gulf of Aqaba and the Red Sea.

Willis[6] is one of the few modern geologists, possessing a first-hand knowledge of parts of the course of Gregory's "Great Rift Valley," to question the conclusions of Suess and Gregory. He states that

> the accumulating facts now indicate that the African Rift valleys are neither topograhically continuous nor certainly attributable to identical causes, and that the Red Sea and Dead Sea are distinct structural depressions which may or may not have similar histories.

Ball[7] denies that either the Nile Valley or the Gulf of Suez are other than erosional features. With reference to the Red Sea, he says

> we have no information which would give us a clue to the origin of this primitive sea, but the inference from the contours is that the *present* extent of the Red Sea has been caused by a great general subsidence of the land, and not by trough-faulting as has hitherto been usually stated.

Barron and Hume,[8] on the other hand, appear to hold that the Red Sea is a trough-fault feature, although the faults, indicated on their maps, while sub-parallel to the coast line, are complicated in trend and do not persist regionally. Similar fault systems have been described also in private reports, by geologists in the employ of various oil companies.

Wissmann[9] has published a geological map of Arabia which depicts a very definite series of faults, both submarine and on land, which parallel the Gulf of Aqaba and the east and west coasts of the Red Sea. These faults are shown as continuous over long distances and swing round, in a rather remarkable manner, from a definitely N. 20° E.–S. 20° W., to a definitely N. 30° W.–S. 30° E., trend at the point where the Gulf of Aqaba enters the Red Sea. This conception of

[5] J. W. Gregory, *The Great Rift Valley*. London (1896).

[6] B. Willis, "The Dead Sea Problem, Rift or Ramp Valley," *Bull. Geol. Soc. America*, Vol. 39 (1928).
———, *Geologic Structures*. New York (second edition, 1929; third edition, 1934).
———, "African Plateaus and Rift Valleys." *Carnegie Inst. Washington* (Washington, 1934).

[7] John Ball, "The Geography and Geology of South Eastern Egypt." *Geol. Survey Egypt*. Cairo (1912).

[8] T. Barron and W. F. Hume, *Notes on the Geology of the Eastern Desert of Egypt*. London (1912).

[9] H. von Wissmann, "Morphologische Probleme in Graben des Roten Meeres," *Zeit. Ges. für Erdk.*, Vols. 9–10. Berlin (1932).

the fault structure had previously been suggested by Blankenhorn,[10] but his maps indicate also (perhaps unintentionally) the existence of east-west faulting on the Hedjaz mainland.

Lamare,[11] as a result of his geological studies in Yemen in the southeast part of the Red Sea littoral, is of the opinion that Argand's[12] modification of Wegener's hypothesis gives the most satisfactory solution to the origin of the Red Sea trough, the cause being "a succession or alternation of folding and tension."

The concensus, therefore, appears to be that the Red Sea trough is a fault feature of some description. Whether it be rift, ramp, or tear is a strongly contested question. The controversy is all the more difficult of solution as a considerable part of the Red Sea littoral is geologically unknown territory. This statement refers especially to the Arabian coast from Aqaba (lat. 29° 35′ N.) southward to Wedj (lat. 26° N.). Even south of this point, as far as Jeddah, the only recorded geology is found in fragmentary notes by travellers. Lawrence's *Seven Pillars of Wisdom* is as good a text-book as any for this latter section, but he did not attempt a systematic geologic description.

The coastal strip of the Hedjaz lying between Jeddah and Aqaba, although uninviting from the traveller's point of view, is of considerable interest to the geologist, particularly as it includes the locality, Ras Fartak (lat. 28° N., approx.), in which the remarkable fault virgation shown on Wissmann's map occurs.

For that reason, the writer is putting on record some of the data collected in that geologically obscure region during the winter of 1936–37, which he spent in field work there accompanied by his colleague, R. Pomeyrol.

HEDJAZ LITTORAL

As already stated, there is no record of any detailed geological study of the eastern littoral of the Gulf of Aqaba, or of that of the Red Sea as far south as Wedj. Isolated notes by travellers and pilgrims are available, however, from very early times, since the main land routes from Egypt to Mecca traversed the area.

A century ago, Wellstead,[13] during an exploratory oceanographic survey of the Gulf of Aqaba, reported the occurrence of gypsum near

[10] Max Blankenhorn, "Die Hedschaz-Bahn auf Grund eigener Reistudien," *Zeit. Ges. für Erdk.* (Berlin, 1907), 2 maps; also, *Geogr. Zeit.* Leipzig (1912).

[11] Pierre Lamare, *Structure Géologique de l'Arabie.* Paris (1936).

[12] Emile Argand, "La Tectonique de l'Asie," *Comp. Rend. XIII. Cong. Géol. Int. Belgique.* Vol. 1. Liège (1924).

[13] J. R. Wellstead, *Travels in Arabia,* 2 Vols. London (1838).

Makna. Similar observations were made by Beke,[14] who was searching for the true Sinai, and by Burton,[15] in his quest for the gold of Ophir. Later, Musil[16] travelled along the coastal fringe from Madian to Aynunah and Sharma, but his lithological descriptions of the clastic beds cropping out along the route he covered are incorrect.

Lawrence in his book, *Seven Pillars of Wisdom*, made several interesting observations of the petrological and topographical features between Jeddah and Wedj. North of that settlement, his duties took him inland.

None of these travellers occupied himself with the tectonics of the region, and it is strongly suspected that the idea of the existence of an "Arabian Wall," with its structural implications, was born of distant observation of the striking coastal scenery of Arabia from the sea. Thus the *Red Sea Pilot*[17] states: "From the Gulf of Akaba . . . this range falls so abruptly on its western face that it presents, towards the sea, a series of inaccessible cliffs." This incorrect statement, harmless enough from the nautical point of view, is quoted by Gregory, and the "Arabian Wall" conception of this coast line has gained universal acceptance, although the form lines on Musil's quite excellent map of the northern Hedjaz are sufficient to indicate its fallacy.

Actually, the transition from the highlands of the Arabian shield massif to the foothills, and on to the detrital and sedimentary beds of the coastal belt, is gradual and the boundary between shield and clastic is extremely irregular. The whole scene, in fact, bears an unmistakable and striking similarity to a buried landscape, and there is little or no suggestion of buried regional faulting trending parallel to the Red Sea coast.

The main direction of faulting observable in the field is east-west, or a few degrees north of west and south of east. Less prominent faulting can be mapped with a north-south trend south of Wedj and gradually veering to N. 20° E.–S. 20° W. as the Gulf of Aqaba is approached.

The effect of these faults is to produce a saw-edge boundary between the rocks of the shield complex and the outcropping Tertiary clastics of the Red Sea littoral. The edges of the "teeth" lie approxi-

[14] Charles Beke, *Sinai in Arabia*. London (1878).

[15] Richard F. Burton, *The Gold Mines of Midian*. London (1878). *Idem*, *The Land of Midian*, 2 Vols. London (1879).

[16] Alois Musil, "The Northern Heğas," *Amer. Geogr. Soc.* New York (1926).

[17] London (1909).

mately east-west and north-south and possess a length in places as great as 20 miles.

That these systems of faulting are largely anterior to the deposition of the Tertiary clastics is proved by the fact that Tertiary fossil fringing reefs, in contact with the shield massif, may be traced round the points of the "teeth" and swing, in many places without any break, from north-south to east-west.

No field evidence of extensive faulting trending parallel with the Red Sea (N. 30° W.–S. 30° E.) has been observed by either the writer or his colleague on any part of the Hedjaz coast line. The direct disproof of the existence of most of the faults appearing on Wissmann's map is difficult, however, as most of them are located either under the Red Sea or traverse areas masked by blown sand or other recent deposits.

It is of interest to note that the north edge of the 360-foot shoal, which has already been noted in the Red Sea at approximately lat. 25° 40′ N., is situated exactly on the seaward extension of one of the best defined east-west faults of the Arabian mainland. This fault can be traced inland along the clearly marked course of the Wadi Hamdth which is one of the most striking valleys of the Hedjaz.

The 100-fathom (600-foot) contour, or, what is practically the same thing, the 200-meter contour of the International map, wherever it can be traced in any detail in the Red Sea, is seen also to possess a saw-edge shape similar to that of the shield-clastic boundary observable on land. This fact is of considerable interest, as the 100-fathom contour represents the depth below which any active coral growth rarely occurs. Once a depth of this magnitude is established in a coral sea, any further submergence results in complete cessation of coral growth in the deep, although the edges of the deep which remain above the 100-fathom line may continue to be built upon to an indefinite extent. In this way, profoundly deep troughs may be formed in coral seas, so long as the activity of coral growth along the margins of the trough can keep pace with the sinking movement.

In many parts of the Red Sea littoral, the shallow coral platform extends seaward as much as 18 miles.

The morphological conditions in the Gulf of Aqaba are very different from those observed in the Red Sea. From Aqaba to Ras Fartak, where the Gulf enters the Red Sea, recent or fossil coral fringing reefs are very limited in extent, the Gulf suffers no striking variations in breadth throughout its length and the 100-fathom contour is almost straight and parallel with the present-day shore lines.

The observable data strongly suggest a trough-fault structure. This appears to be a direct continuation of the Jordan valley structure, which has been described by many geologists in both public and private reports.

CONCLUSIONS

The data collected in the hitherto unstudied Hedjaz littoral area confirm the suggestion postulated by Willis that the Gulf of Aqaba and the Red Sea are not only topographically distinct units, but that their origins are tectonically different.

If the Gulf of Aqaba is accepted as a rift or ramp fault feature, it is only logical to assume some other origin for the Red Sea depression.

Any excursions into the realms of theory have purposely been avoided in this paper, and an attempt has been made to confine the material to facts observed in the field during an all too short expedition of 4 months. It may be stated, however, that no evidence conflicting with the thesis that the Gulf of Aqaba is either a rift or a ramp fault feature has been noted. To determine which of these it may be will require much more intensive study of the complex field data than was possible in the short time available. It is possible that both rift and ramp conditions occurred during different stages of its history.

As regards the Red Sea, the "Arabian Wall" is a pernicious myth, and no field evidence has been observed, in the Hedjaz, of major faulting parallel to that body of water. If such faults exist, they are so completely masked by sea and detritus that speculation concerning them ill becomes a field geologist working with outcrop evidence.

Lamare's suggestion of folding, followed by tearing, appears to fit the facts well, particularly if sufficient emphasis is placed on the effects of contemporaneous erosion and on the peculiarities of coral growth.

The dips observed on the Hedjaz coast and on the offshore islands, in combination with those given in the various published papers and private reports, made available to the writer, on Sinai and the Egyptian littoral, combine to indicate that the Red Sea, and to a less certain extent the Gulf of Aqaba, are located on major axes of anticlinal folds. That conclusion fits in equally with the "ramp" and "fold and tear" hypotheses and does not eliminate a rift origin.

A further fact, not as supporting any of the conflicting theories but as proof of rhythmic movement, is of interest. In lat. 24° N., the upper limit of the marine or lagoonal strata is only approximately 30 feet above sea-level. The height of this limit increases northward until it is nearly 1,000 feet above sea-level at the Gulf of Aqaba, thus proving that both positive and negative tilting, on an approximately east-west axis, has occurred during Tertiary and Recent time.

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GEOLOGICAL SUCCESSION OF CENTRAL VENEZUELA[1]

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ABSTRACT

The geology of Venezuela is treated as a study of three tectonic phases: the schistose Coast Range; the foothill sections; the post-foothill sequence. These are sketched in relationship to the main geosyncline, their problems stated, and recommendations made relevant to those problems.

INTRODUCTION

The following notes are written with no technical literature at hand, references being only inferred without formal bibliography. The object of these notes is to place in review the status of geological problems in central Venezuela; hence to invite discussion on such opinions as may here be expressed.

The writer acknowledges the privilege of his contacts with other geologists, especially at the first Venezuelan Geological Congress early in 1937.

GENERAL CONSIDERATIONS

The geological problems of central Venezuela are the problems of a thrust, although not over-riding, mass of schistose material in the north and its consequent basins of sedimentation farther south. These basins have their southern rims feathered out against the lip of an igneous complex generally stated to be part of the Brazilian shield or crystalline massif. The basins of central Venezuela are merely sectors across a tremendously extensive geosyncline which swings round to the west between the Venezuelan Andes and the upper Orinoco waters. Beyond this reach, the geosyncline parallels the Andes proper perhaps as far south as Ecuador. East of central Venezuela, it is presumed that the same depression lies across the Orinoco delta and is associated with the oil deposits of Trinidad. In central Venezuela, however, a focal point of interest is added by the igneous mass around El Baul which may be said to split the normal geosyncline. A major problem in the paleogeography of central Venezuela arises with the presence of this mass. It becomes necessary to decide whether the El Baul mass stood out on the north as a promontory of the primal Brazilian shield, or whether it was upthrust in the forefront of those upheavals which elevated the schistose Coast Range. The classic methods of determining the dynamic relationships at El Baul by the surface mapping of the contact sediments is here vitiated by a com-

[1] Read by title before the Association at New Orleans, March 18, 1938. Published by permission of the Caracas Petroleum Corporation. Manuscript received, March 25, 1938.

[2] Geologist, Caracas Petroleum Corporation.

plete overlap of plains or "llanos" material. The result of this overlap is to give the El Baul complex the effect of a monadnock. The problem should be largely solvable by the comparatively inexpensive method of radiating torsion-balance profiles from various points at the foot of the mass. The high density of the igneous material would be suitable for obtaining reasonably distinctive gravitational data at moderate depths.

COAST RANGE COMPLEX

The term "Coast Range complex" is here reserved for the schistose mass of the upthrust which borders the Caribbean coast in central Venezuela. On the north, in many places the schists extend to the coast line itself, while the southern boundaries may be taken as the first appearance of true sedimentary material. Granitic cores in this schistose material are exposed in places but metamorphism is not advanced, even at the contacts themselves. It is possible therefore that true sediments were laid down over coastal granite, and the two elevated together in thrust movements. Despite lack of advanced metamorphism, the pressure developed may have been sufficient to destroy all traces of organic remains in the sediments which were stressed until they became schists. The problem of the age, or of the several ages, of the Coast Range beds must therefore be largely speculative. Certain inferences might be attempted. Thus the Venezuelan Andes farther west are fringed on their southeast flank by proved Paleozoic deposits in outcrop. It might therefore be inferred that part of the schistose mass of Venezuela was once sediment in Paleozoic seas; further, that the southern shores of these seas may not have been distant from the present central Venezuelan coastline. Alternatively, prolongation of a southeastern flank line of the Venezuelan Andes suggests that the Paleozoic seas swept out northeastward. This would mean that they were off the locus of the movement which gave rise to the Coast Range. On this supposition it would be necessary to name the schists of the Coast Range as either pre-Cambrian or post-Paleozoic. This reasoning is based on the assumption that if both pre-Cambrian and post-Paleozoic were present, two distinct phases of thrusting might be expected in exposure. This is not the fact, at least in the light of admittedly very cursory examinations.

Comparision between the Venezuelan Andes and the Coast Range should also be made on a tectonic basis. In a simple manner, the Venezuelan Andes may be viewed as a vertical uplift from whose main plug sediments are thrust off both northwest and southwest. This contrasts sharply with the Coast Range of central Venezuela. In

the latter, the thrust is totally southward, and the north flank appears to be down-dropped toward the Caribbean deeps. On such reasoning, the two ranges are separate orogenic provinces. To what degree differences in orogeny are criteria for differences in stratigraphy is left as an open question by the writer.

In this problem of the age of the Coast Range, it is noteworthy that the forward or southern flank of the schistose mass has attracted the attention of many geologists. In particular, attention has been drawn to exposures of thin flaggy impure limestones and black calcareous shales which have been thrown into characteristic contorted folds. These have been compared lithologically with less metamorphosed sediments of proved Cretaceous age farther basinward in the foothill phase of the coastal movements. The lithological comparision is entirely just in the field and may be the precursor to more definite evidence as work proceeds. The line of attack for this problem appears to be the making of numerous thin sections both along the line of strike and across thrust in the flaggy limestone members of the Coast Range southern flank. Micro-organic material may appear in such thin sections and may then be compared with similar micro-organic material from true Cretaceous beds. Indeed, the whole mass of the two Venezuelan ranges should be comprehensively sampled, including the known Paleozoic which should yield type mineral residues of considerable value.

FOOTHILL ZONE OF COAST RANGE

For clearness of definition, the foothills of central Venezuela are here taken as comprising the belt of deformed but unmetamorphosed sediments which immediately succeed the Coast Range schistose masses on their inland flank. These unmetamorphosed sediments are repeatedly thrust in smaller and larger imbrications and schuppen, perhaps as far as the point where they are overlapped by much later sediments in the south. The formations included in these buckled sediments range from Cretaceous to pre-late Tertiary in age.

The Cretaceous sections have been studied by geologists in some detail across many sections of central Venezuela. The whole of the system may not be exposed, or it may be metamorphosed in its basal sections. However, the appearance of white saccharoidal sandstones in eastern Venezuela has been taken as marking the lower third of the system. Organic remains in the saccharoidal sandstones are scarce, unless plant markings be included. A comparsion of the mineral residues of these sandstones and comparison with the insoluble residues of overlying limestones might prove of interest. In contrast, the lime-

stones, cherts, and shales of the younger Cretaceous sections consistently yield mollusks, ammonites, and micro-organisms where they are examined with care. The uniformity of the limestone-chert-shale facies across broad belts of territory is distinctive not only for central Venezuela but for Venezuela as a whole.

Of the basal or Lower Cretaceous sandstone, it has been justifiably claimed that it grades out laterally to the west, being replaced by an equivalent metamorphosed zone.

Possibly, this is a conclusion reached from the study of small-scale maps. Actually tracing the Lower Cretaceous sandstone westward in the field might yield data of value. It might also yield data helping to elucidate the age of the Coast Range southern flank.

Since the strata of the foothill belt are repeated at short intervals by small and large thrusts, elucidation of the stratigraphical succession is attended with difficulties. In spite of this, data of much value probably will be obtained after detailed field work. Thus certain geologists have indicated that an increasing ratio of quartzitic material in the beds marks the highest levels of the Cretaceous system at specified localities in central Venezuela. Faced with the problem of accounting for at least a part of the Eocene period of deposition, they have reasonably taken the appearance of quartzitic bands as the equivalent of proved Eocene elsewhere in Venezuela. Calcareous material and dark shales remain associated with the quartzitic layers so that the transition is apparently unbroken. Persistent examination of the shales across the transition for micro-fauna should yield evidence which may throw further light on the question of early Eocene deposition in central Venezuela. It is interesting to note that a casual sample recently taken by the writer behind a thrust not far from post-quartzitic beds yielded foraminifera which were comparable with the Upper Cretaceous of Mexico. Long-range comparisons such as these are entirely hazardous, but the possibilities of organized collecting across the presumed Cretaceous-Eocene transition are indicated.

The transition material described in the foregoing paragraph is followed southward across thrust contacts by a series in which well formed sandstone members are prominent. This series is generally known as the Ortiz formation, a name proposed by Liddle after the town of Ortiz. Actually the Ortiz formation may not be present at Ortiz itself but the name can well be retained as referring to the municipality of Ortiz. The block nature of the sandstones gives rise to distinctive scarps, even in the smaller outcrops; but the percentage of sandstone in the formation may be less than the literature appears to indicate. Thus it is possible that the ratio of sandstone to clay or

clay-shale material may be as small as 1:20. This is further indicated by the velocity of refracted waves across the composite formation in outcrop, an average velocity being little more than 10,000 feet per second. The sandstones vary in grain size but rarely approach conglomerate and are notably feldspathic at certain horizons. Since ripple-marking in the sandstones is a prominent feature, the formation may be taken as truly marine although of inshore environment. Unfortunately, fossils other than inswept plants are either scarce or entirely absent in the majority of central Venezuelan outcrops.

The age of the Ortiz formation must be considered a major problem in the stratigraphy of central Venezuela. The placing of the formation wholly in the Eocene is perhaps too simple an answer. If the quartzitic horizons of the underlying sections are partly Eocene in age, there is a sharp break within the Eocene system. In terms of lithology, this is a break between the rocks with quartzite-shale-flag lithologic character and the rocks with a moderately dense sandstone-clay-shale lithologic character such as represented in the Ortiz unit. In better known areas both east and west of central Venezuela, Trinidad included, most geologists concede an important break in the Eocene succession. It could therefore be argued that the Eocene embraced a period sufficiently large to accommodate the Ortiz unit in its second or recurrent phase of sedimentation. With reference to this, the writer notes that in one section of the foothills he has measured between 7,000 and 10,000 feet of beds which are apparently wholly within the single lithological unit represented by the Ortiz formation. Such thicknesses suggest the possibility that the Ortiz formation crosses the time-line elsewhere represented by Eocene-Oligocene transition. There are characteristics in the mineral residues of a few Ortiz formation samples which indicate that this latter is a hypothesis worthy of investigation. The writer's results on this point are, however, meager at present. Here, again, persistent examination of clays may help in elucidating the problem. As for investigations proposed earlier in this paper, the lateral variation in mineralogy and microorganic content must be studied for great distances along the general strikes. Although the source of mineral residues may vary along great distances, the regularity of shallow marine conditions in the Ortiz unit promises a certain amount of mixing parallel to the Ortiz coastlines. The mineral residues resulting from such mixing should reveal variations not too abrupt for general correlation purposes. If this examination of suites is carried east into Anzoategui, it must enter equivalent formations of different facies, but of better defined paleontology. These latter sections could then be used as reference types.

Here and there Ortiz types of strata are closely associated in the

field with orbitoidal limestones. This association has influenced the opinion of many geologists in placing the Ortiz formation wholly within the Eocene. Although the association is unquestionable, the actual stratigraphical relationships involved are problematical. In those places observed by the writer, the orbitoidal limestone has been brought up by thrusting, and the exposed sandstones near it might well be higher in the succession.

POST-ORTIZ ZONES

The post-Ortiz zones of central Venezuela are here defined as slightly disturbed areas in which either elementary folding or simple tilting may take place. At the most southerly edges of the Ortiz unit or its equivalents, the post-Ortiz zones are sharply upturned and probably faulted where the strength of the Coast Range movements are almost spent. The age of these disturbed post-Ortiz beds is problematical. The writer has found a few small pelecypods near the sharp upturnings, but their stratigraphical value is probably small. Elsewhere, pelecypods occur in abundance in calcareous sandstone members of strata equivalent to the upturned beds. Even though it is true that the fauna thus obtained is comparable in genetic and even in specific characters with Middle Miocene types from Bowden, Jamaica, it must also be remembered that many of the forms are still living. Perhaps the classic method of taking percentages of living forms in the fauna might help to obtain a more reasonable estimate of the age. As the calcareous group is traced eastward, its relationship to Lower Miocene foraminiferal beds suggests that it may be very late in the Miocene. Even a Mio-Pliocene age has been suggested, and for the present finds some favor with the writer.

The large area covered by these Mio-Pliocene beds must include the residual folding undergone by pre-Pliocene beds well south of the foothills as they experienced slight resistance from the gently sloping Orinoco buttresses in their path. A problem which has long attracted the oil companies over large tracts of territory is that of deciding whether the Mio-Pliocene beds reflect the structure of underlying strata. Accurate mapping of the beds is made difficult by the fact that in many places the sandstone members are indistinguishable one from another. Further, these sandstone members occur mainly as erosional remnants so that no continuity can be traced in them. Reliance must therefore be placed on dips for the interpretation of structure. Unfortunately, the calcareous nature of the sandstones tends to produce ragged outcrops. In some places, undercut solution boulders are produced. Correlation by digging pits has been attempted by more than one company, but, presumably, great detail must be

necessary to discount the effects of slumping in individual pits. Nevertheless, structures have been submitted by geologists for many years on surface evidence obtained from end to end of the extensive Mio-Pliocene outcrop. The value of this structural mapping will emerge only as geophysical investigations adequately cover those areas already mapped in sufficient detail.

The geology of post-Mio-Pliocene, or post-calcareous, beds offers a further problem. In south-central Venezuela, they occur largely as upland strips of mesa comparable with the extensive llanos of eastern Venezuela. In central Venezuela, however, there is evidence of tilting in these mesa beds which may be seen in long-distance views or by survey measurement. No evidence is as yet at hand for determining the age of these deposits, although in places the writer has found leaf remains in the clays. General considerations suggest that the beds are Pliocene. Nevertheless, it has still to be proved that they are not estuarine or shallow-water equivalents of Quaternary fluviatile materials elsewhere in the Venezuelan succession.

The tilting of these mesa beds suggests that movements persisted at least into the latest Tertiary and possibly into the Quaternary of south-central Venezuela. The movements should be compared with the coastal down-faulting mentioned before in these notes. This down-faulting was still active in Pleistocene time as evidenced by sharp upturning of Quaternary mollusk beds on the Caribbean shore, presumably complementary to the final phases of upthrusting in the schistose Coast Range. In south-central Venezuela, however, the post-Mio-Pliocene mesa is far removed from the focus of coastal mountain-building. It is therefore necessary to speculate whether gentle readjustments took place on the sloping north lip of the primal igneous shield during Tertiary-Quaternary time, such as would have been sufficient to tilt the mesas.

The post-Mio-Pliocene beds are notable for their loose conglomerates or regularly stratified gravel beds. The gravel is largely of milky white quartz, whereupon the question arises as to the source of this quartz. Of the known beds in the foothill sections, neither the Ortiz units nor the Cretaceous-Eocene beds are notable for their vein-quartz content. It is possible that vein-quartz exists freely in the Coast Range schists but this is not the writer's impression although his knowledge of the schists is admittedly limited. Examination of mineral residues in the post-Mio-Pliocene sands and comparison of their contents with those of sandy phases in the schist section might yield information. Interesting evidence might also be obtained by comparing thin sections of quartz gravel with thin sections of quartz vein material in the Coast Range.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 9 (SEPTEMBER, 1938), PP. 1231-1235, 1 FIG.

FURTHER DATA ON WILDCAT DRILLING IN 1937[1]

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ABSTRACT

This is an extension of the earlier article on the subject of wildcat drilling in 1937, published in June, 1938. In the present paper attention is given to all of the United States except the northeastern states. A comparison is made of the number of producers and dry holes drilled on technical and non-technical advice.

In the June number of this *Bulletin* for 1938, on pages 645–48, we published a summary on wildcat drilling in 1937 for a considerable part of the Gulf Coastal Plain of the United States. The results were so interesting to many that the study was carried into other states where drilling for oil is active. We offer here a résumé of this extended investigation, together with statistics from the earlier paper. The following states are included: California, Montana, Wyoming, Colorado, Utah, western Nebraska, northwestern New Mexico; Kansas, Oklahoma, Illinois, Michigan, Indiana, Kentucky, Tennessee; and the states covered by our report in the June *Bulletin*, namely, southeastern New Mexico, part of Texas, southern Arkansas, Louisiana, Mississippi, Alabama, and Florida. To the data for Texas has been added information on all the rest of the state except a few relatively unimportant central counties. In the figures presented herewith, Ohio and states farther east have not been included.

We remind the reader that, as in the earlier articles on this subject, we are using the word "wildcat," meaning a hole drilled for oil or gas and sufficiently far from any developed production to be a test of unknown subsurface conditions. We do not include short extensions of pools, or any holes located within the boundaries of pools unless, as in a few instances, such holes were drilled to explore untested possibilities distinctly deeper than the known pay horizons.

Table I gives a summary of the data, and Figure 1 presents some of the facts in more graphic form. Of the 2,224 wildcats drilled in 1937 in the area covered by this report, 1,943 (87.37 per cent) were dry, 222 (9.98 per cent) discovered oil, and 59 (2.65 per cent) discovered gas. The total footage drilled was 8,387,615 feet, divided as follows: dry holes, 7,173,550 feet (85.52 per cent); oil discovery wells, 938,440 feet (11.19 per cent); and gas discovery wells, 275,625 feet (3.29 per cent). For every producer-foot drilled, 5.9 feet of dry hole were drilled.

[1] Manuscript received, July 18, 1938.

[2] Chief geologist, Sun Oil Company.

TABLE I

NUMBER OF OIL WELLS, GAS WELLS, AND DRY HOLES DRILLED AS WILDCATS IN 1937

Districts	Oil		Gas		Dry		Total No. of Holes	Total Footage Drilled
	No. of Holes	Footage Drilled	No. of Holes	Footage Drilled	No. of Holes	Footage Drilled		
Alabama	0	—	0	—	2	7,248	2	7,248
So. Arkansas	5	32,386	0	—	44	156,042	49	188,428
California	8	48,949	2	10,661	140	649,679	150	709,289
Florida	0	—	0	—	3	6,379	3	6,379
Illinois	22	56,955	0	—	105	226,564	127	283,519
Indiana	2	3,201	2	1,950	27	28,793	31	33,944
Kansas	29	102,226	0	—	194	756,189	223	858,415
No. Louisiana	1	9,048	5	32,950	51	240,796	57	282,794
So. Louisiana	13	122,502	5	46,600	67	503,110	85	672,212
Michigan	9	22,519	1	1,323	80	227,216	90	251,058
Mississippi	0	—	0	—	19	72,628	19	72,628
SE. New Mexico	3	12,061	0	—	40	135,479	43	147,540
Oklahoma	21	83,752	7	18,837	146	596,257	174	698,846
Rocky Mtn. States								
Colorado	1	6,710	0	—	10	39,390	11	46,100
Montana	0	—	1	2,592	5	18,561	6	21,153
Nebraska	0	—	0	—	1	3,999	1	3,999
NW. New Mexico	0	—	1	2,112	23	34,377	24	36,489
Utah	0	—	0	—	1	4,900	1	4,900
Wyoming	2	8,325	1	2,187	11	42,659	14	53,171
Total Rky. Mtn. Area	3	15,035	3	6,891	51	143,886	57	165,812
Tennessee	2	1,760	3	2,013	10	13,162	15	16,935
Texas								
Wichita Falls	24	61,694	4	7,745	180	413,134	208	482,573
Panhandle	0	—	1	2,864	8	21,680	9	24,544
NE. Texas	16	57,922	6	40,894	105	405,132	127	503,948
SE. Texas	13	93,668	7	48,147	109	639,105	129	780,920
SW. Texas	31	139,659	13	54,750	325	1,216,832	369	1,411,241
San Antonio	8	23,013	0	—	128	292,324	136	315,337
West Texas	12	52,090	0	—	109	421,915	121	474,005
Total Texas	104	428,046	31	154,400	964	3,410,122	1,099	3,992,568
Total	222	938,440	59	275,625	1,943	7,173,550	2,224	8,387,615
Per Cent of Total	9.98	11.19	2.65	3.29	87.37	85.52		

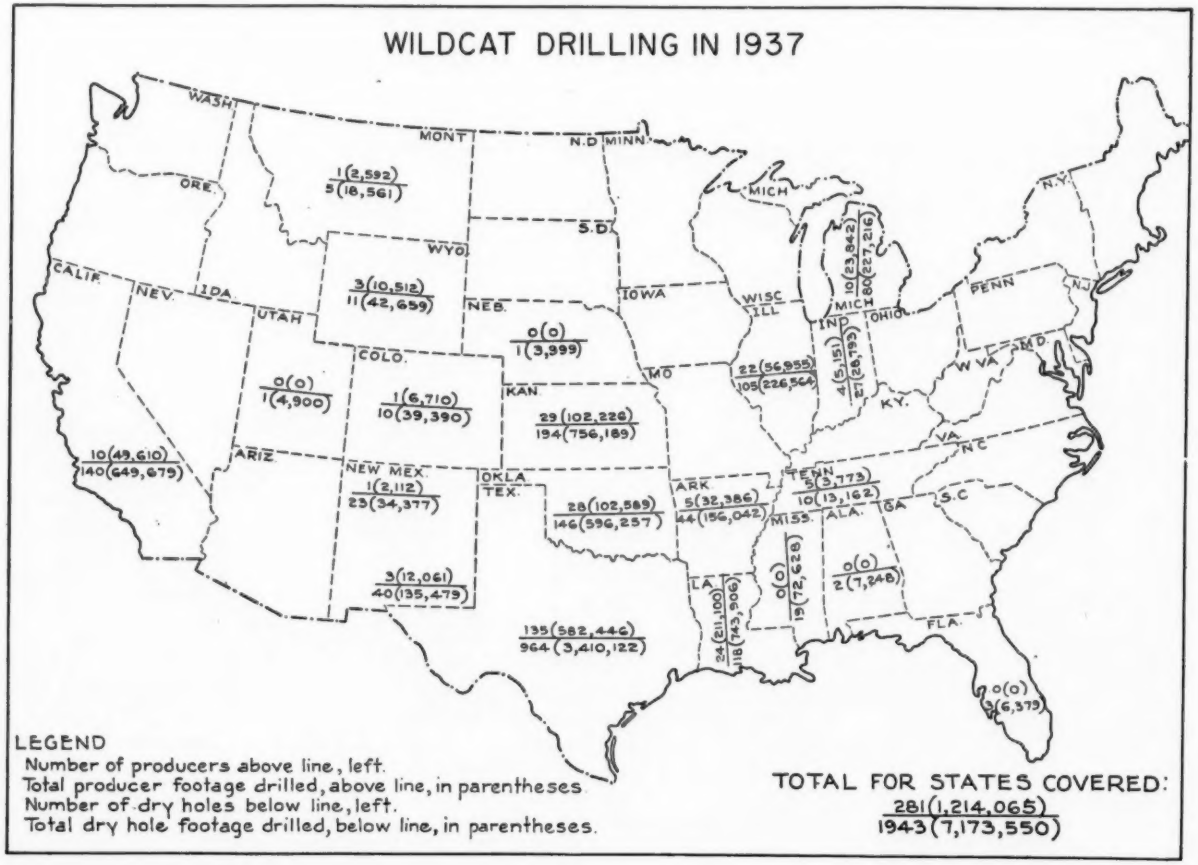
WILDCAT DRILLING IN 1937
WASH
ORE
CALIF
NEV
IDA
MONT
1 (2,592)
5 (18,561)
WYO
3 (10,512)
11 (42,659)
UTAH
COLO
0 (0)
1 (4,900)
1 (6,710)
10 (39,390)
ARIZ
10 (49,610)
140 (649,679)
NEW MEX
1 (2,112)
23 (34,377)
3 (12,061)
40 (135,479)
N.D
MINN
S.D
NEB
0 (0)
1 (3,999)
KAN
23 (102,226)
194 (756,189)
OKLA
TEX
28 (102,589)
146 (596,257)
135 (582,446)
964 (3,410,122)
IOWA
MO
ARK
5 (32,386)
44 (156,042)
LA
24 (211,100)
118 (743,906)
MICH
WISC
ILL
22 (56,955)
105 (226,564)
IND
4 (5,151)
21 (28,795)
10 (23,942)
80 (227,216)
OHIO
KY
TENN
5 (3,773)
10 (13,162)
MISS
0 (0)
19 (72,628)
ALA
0 (0)
2 (7,248)
GA
S.C
FLA
0 (0)
3 (6,379)
W VA
VA
N.C
PENN
N.Y
N.J
MD
LEGEND
Number of producers above line, left.
Total producer footage drilled, above line, in parentheses.
Number of dry holes below line, left.
Total dry hole footage drilled, below line, in parentheses.
TOTAL FOR STATES COVERED:
281 (1,214,065)
1943 (7,173,550)

FIG. 1

TABLE II

BASIS FOR LOCATING WILDCATS DRILLED IN 1937

State	Geology		Geophysics		Geology and Geophysics		Sundry*		Unknown		Totals	
	Dry	Prod.	Dry	Prod.	Dry	Prod.	Dry	Prod.	Dry	Prod.	Dry	Prod.
Alabama	—	—	—	—	1	—	1	—	—	—	2	—
So. Arkansas	14	1	10	4	—	—	3	—	17	—	44	5
California	76	3	14	2	14	3	—	—	36	2	140	10
Colorado	8	1	2	—	—	—	—	—	—	—	10	1
Florida	—	—	—	—	1	—	1	—	1	—	3	0
Illinois	15	2	18	9	2	1	—	—	70	10	105	22
Indiana	12	2	1	—	—	—	—	—	14	2	27	4
Kansas	47	14	18	3	3	2	—	—	126	10	194	29
Louisiana	49	3	36	16	7	5	11	—	9	—	112	24
Michigan	62	8	—	—	—	—	16	2	2	—	80	10
Mississippi	5	—	4	—	5	—	3	—	2	—	19	0
Montana	4	1	—	—	1	—	—	—	—	—	5	1
Nebraska	1	—	—	—	—	—	—	—	—	—	1	0
SE. New Mex.	7	—	2	—	1	—	—	—	30	3	40	3
NW. New Mex.	2	—	—	—	—	—	—	—	21	1	23	1
Oklahoma	54	13	42	13	1	—	49	2	—	—	146	28
Tennessee	7	3	—	—	—	—	—	—	3	2	10	5
Texas	491	62	89	35	29	4	194	13	167	21	970	135
Utah	1	—	—	—	—	—	—	—	—	—	1	0
Wyoming	6	3	4	—	1	—	—	—	—	—	11	3
Totals	861	116	240	82	66	15	278	17	498	51	1,943	281

* Various reasons, including reported showings in dry holes previously drilled, lease requirements promotion schemes, "hunches," "doodle bugs," *et cetera*.

Analysis was made of the reasons, or basis, for drilling these wildcats. Such information, coming from various sources and being in some degree subject to personal interpretation, can not be 100 per cent accurate, but we feel that it gives a reasonably true picture. In Table II, the data on reasons for locating the 2,224 wildcats are summarized. The reader will note that 116 discovery wells and 861 dry holes were located on geology (surface, subsurface, trend, core drilling); 82 discovery wells and 240 dry holes were located on geophysics (seismograph, torsion balance, gravity meter, magnetometer, and combinations); 15 discovery wells and 66 dry holes were located on combined geological and geophysical evidence; 17 discovery wells and 278 dry holes were located for sundry reasons (lease requirements, showings in old wells, promotion schemes, "hunches," *et cetera*); and 51 discovery wells and 498 dry holes were located for reasons not known to those who assembled the information.

Part of this last classification would no doubt fall in one of the first three columns, and part would fall in the fourth. Not knowing into which group to place them, we shall therefore omit these 498 dry holes and 51 producers in the following statement. Of the holes located on other than a technical basis, 6.1 per cent were successful in finding oil or gas; whereas, of the holes located on technical advice, 18.3 per cent discovered oil or gas. For the whole region embraced in this report, then, locations based on technical advice were three times as successful as locations made without such advice.

For much of the information which made this article possible, and for interested suggestions and assistance, the writer is indebted to John G. Bartram, A. H. Bell, K. E. Born, A. E. Brainerd, R. J. Cullen, M. M. Fidler, G. C. Gester, H. W. Hoots, Edward A. Koester, J. J. Maucini, and George W. Myers.

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CORRECTIONS IN ARTICLE ON "WILDCAT DRILLING IN 1935 AND 1936," PUBLISHED IN THE BULLETIN PAGES 1079–1082, AUGUST, 1937

Through some oversight, an error appeared in the addition of dry hole footage for District *A* (including 1, 2, 3, and 6) in the table appearing on page 1080 of the *Bulletin* for 1937. The figure in the right-hand column, opposite *A*, should be 221,080 instead of 419,795. As a result of this error the total for the column on dry hole footage is also wrong. It should be 3,415,296 instead of 3,614,011. A few other mistakes resulted from this error. Corrections should be made as follows.

In Figure 1, in the parenthesis under the line for "total," just to the right of the map, the figure should be 3,415,296 instead of 3,614,011. Just under this the statement should read "one producer foot for every 9.63 feet dry."

At the right of the map in Figure 2, the statement should read "one producer foot for every 6.80 feet dry."

On page 1080, at the bottom of the column for "Per Cent Producing Footage" the figure should be 9.417 instead of 8.940; and in the next column to the right, for "Per Cent Dry Footage," the figure should be 90.583 instead of 91.060.

In the footnote under the column on page 1080, second line, the figure should be 9.63, instead of 10.31, feet of dry hole.

On page 1081, in the second line of the footnote under the table, the figure should be 6.80 instead of 6.83.

On page 1082, second paragraph, fifth line, the figure should be 3,415,296 instead of 3,614,011. In the same paragraph, third line from the bottom, at the end of the line, the figure should be 9.63 instead of 10.31. In the last line of this paragraph the figure should be 6.80 instead of 6.83.

A quotation was made from this article in the contribution on "Wildcat Drilling in 1937," published in June, 1938. On page 647, Volume 22, of the *Bulletin*, in the tenth line, the figure should be 6.80 instead of 6.83.

FREDERIC H. LAHEE

DALLAS, TEXAS
July 18, 1938

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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BEHAVIOR OF FLUIDS IN OIL RESERVOIRS[1]

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ABSTRACT

It is suggested that greater recovery of oil will be obtained: (1) by maintaining the pressure of the reservoir at high values, (2) by keeping gas, oil, and water segregated in their natural relation as far as possible.

To bring about these conditions, low rates of flow are essential, especially in water-drive fields. Likewise, free gas and water should not be produced. The mechanism by which gas and water enter wells may be either one of movement in mass through parts of the sand containing little or no oil, or one of movement with the oil through sands containing oil with water or free gas. Production of gas or water by the first method can often be prevented by repair of the well, whereas little can be done to control these fluids if the second mechanism is responsible for their production. As high rates of flow tend to bring about commingling of free gas and water with the oil, they may cause a premature development of high gas-oil or water-oil ratios.

Completion of wells should be given careful attention, and completion and repair operations should be governed by the structure of the reservoir and the condition and nature of the fluids therein. Proper consideration of these factors will result in more successful operations and in greater oil recovery from a field.

This paper presents a review of some of the important recent investigations of the flow of oil, gas, and water through sands, and discusses the application of the results to the problems of oil recovery. Although the flow of homogeneous fluids through sands is fairly well understood, the pores of oil-bearing sand always contain two and generally three fluid phases: oil, gas, and water. Flow under these conditions is so complex that it is impossible, with present knowledge, to solve quantitatively anything but the simplest problems of two-phase flow. However, it is possible to demonstrate some of the qualitative principles that govern the flow of oil even in the complex cases met in practice. To do this is an object of this discussion.

At least two conditions are necessary to permit the flow of oil to a well.

1. An hydraulic gradient must exist between the well bore and the surrounding sand.

2. The oil saturation of the sands in the neighborhood of the well must be sufficiently high to permit flow of oil with, or in preference to, the other fluids within the sand.

The first condition can be met as long as the reservoir pressure is maintained; the second as long as a sufficiently high concentration of oil in the vicinity of the wells is maintained.

[1] Read before the Association at New Orleans, March 17, 1938. Manuscript received, March 16, 1938.

[2] Humble Oil and Refining Company.

MAINTENANCE OF RESERVOIR PRESSURE

The maintenance of reservoir pressure is one of the most important requirements that must be met in order to obtain high recovery from an oil field. Most initial reservoir pressures are approximately equivalent to the hydrostatic head of a column of water of a height equal to the depth of the field,[3,4] or approximately 460 pounds per 1,000 feet of depth. Some gas always occurs with the oil, ordinarily in excess of the quantity necessary to saturate the oil at the initial reservoir pressure, in which case a gas cap is present; but in some places, notably in the East Texas[5] and Talco fields, there is insufficient gas for complete saturation of the oil. As the pressure is lowered, the fluids in the reservoir expand, being forced to the wells through which they may be produced. The degree of pressure reduction that occurs with the production of a definite quantity of oil depends on several factors, but, in the absence of water drive, is controlled primarily by the expansive power of the gas associated with the oil. If pressure is to be maintained, the expansive power of the gas must be maintained; hence, the oil must be produced with low gas-oil ratio. The quantitative effect of gas-oil ratio on reservoir pressure was studied by Coleman, Wilde, and T. W. Moore,[6] whose work has been extended and amplified by others.[7,8,9] These investigators have clearly demonstrated the necessity, in fields not under water drive, either for low average gas-oil ratios throughout the producing life or for maintenance of pressure by return of gas in such fields.

In water-drive fields, pressures may be maintained by a proper control of the production rate from the field.[7,10,11] In this type of field,

[3] G. E. Cannon and R. C. Craze, "Relation of Pressure and Depth in the Gulf Coast," presented before Amer. Inst. Min. Met. Eng., February, 1938.

[4] W. E. V. Abraham, "Problems of Deep Well Drilling," *Jour. Inst. Petrol. Tech.* (July, 1937).

[5] B. E. Lindsly, "A Study of Bottom Hole Samples of Crude Oil," *U. S. Bur. Mines R. I. 3212.*

[6] Coleman, Wilde, and T. W. Moore, "Quantitative Effect of Gas-Oil Ratio on the Decline of Average Rock Pressure," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 86 (1930), p. 174.

[7] R. J. Schilthuis, "Active Oil and Reservoir Energy," *Petroleum Development and Technology, 1936.* (Amer. Inst. Min. Met. Eng.), p. 33.

[8] D. L. Katz, "A Method of Estimating Oil and Gas Reserves," *ibid.*, p. 18.

[9] B. H. Sage and W. N. Lacey, "Application of Phase Equilibrium Data to Estimation of Oil and Gas Reserves," Seventh Midyear Meeting Amer. Petrol. Inst.

[10] G. L. Nye and C. E. Reistle, "Recent Changes in Reservoir Pressure Conditions in the East Texas Field," *Petroleum Development and Technology, 1934* (Amer. Inst. Min. Met. Eng.), p. 77.

[11] R. J. Schilthuis and W. Hurst, "Variations in Reservoir Pressure Conditions in the East Texas Field," *ibid., 1935*, p. 164.

water, in the same reservoir as the oil, is initially in hydraulic equilibrium with the oil, but as the oil is produced, the pressure on the oil zone is lowered, and the water tends to move into the zone of reduced pressure. The rate of water intrusion is approximately proportional to the reduction in pressure in the oil zone, and the effect of the water entering the oil zone is to compress the remaining oil and gas and thus maintain higher pressures. If the rate of water intrusion equals the rate of volumetric withdrawal (volume of oil, gas, and water withdrawn under reservoir conditions), a constant pressure will prevail in the oil zone. The higher the rate of production, the lower is the equilibrium pressure thus established. Within limits, the effect of changing the rate of withdrawal is to cause a comparatively rapid change in pressure from the equilibrium value at the initial rate to that correspondent with the final rate, after which little further change in pressure occurs. Data illustrating this in the East Texas field have been published.[11] However, it can be demonstrated that the establishment of an equilibrium pressure by a balance between volumetric withdrawal and water intrusion can take place only at rates of oil withdrawal below a definite value. At higher rates, the increase in volumetric withdrawal due to expansion of the oil and gas after reduction of pressure is greater than the increased rate of water intrusion due to the same reduction in pressure. This causes further reduction in pressure, which causes still further disparity between the volumetric withdrawal and water intrusion, thus rendering maintenance of pressure by water drive impossible. In fact, at rates much higher than the critical value at which pressure can not be maintained, the decline in reservoir pressure follows much the same course as it would if no water drive at all were present. In many water-drive fields in Texas, the rate at which water can not maintain pressure is at a production of about 5–7 per cent of the field's recoverable reserves per year.

It is important to observe that low gas-oil ratios are also essential in maintaining pressure by water drive, because of the reduced ratio of volumetric withdrawal to oil withdrawal. For the same reason, the production of water should be kept at a minimum.[12,13] Summarizing, two factors are essential in the prevention of excessive pressure decline in oil fields: (1) control of rate of withdrawal in water-drive fields; (2) production with low gas-oil and low water-oil ratios.

[12] T. V. Moore, "Application of the Principle of Volumetric Withdrawal to the Allocation of Production," *Drilling and Production Practice, 1934* (Amer. Petrol. Inst.), p. 23.

[13] D. R. Knowlton, "Effect of Volumetric Withdrawal on Physical Waste in the Oklahoma City Field," *ibid.*, p. 28.

Little need be said about the methods of controlling production rates. Ordinarily, the effect of production rate upon pressure can be estimated,[7,9,11] and the desirability of using slow production as a means of maintaining reservoir pressure can be evaluated with fair accuracy. In practice, the production rate of most important domestic fields is set by State authority.

NATURE OF OIL RESERVOIRS

Control of gas and water presents a difficult problem, although one which must be successfully solved if high recovery is to be obtained. The excessive production of these fluids not only causes a rapid decline of pressure, but also, as was previously pointed out, it may prevent oil which otherwise might be recoverable from entering the wells. The common causes of excessive gas or water production may be listed as follows.

1. Sections of the reservoir bearing free gas or water are open to the well.

2. Gas or water, due to the low pressure prevailing in the neighborhood of the well, cone into the well.

3. The oil saturation in the neighborhood of the wells has become too low to permit the flow of oil to occur in preference to the water or gas in the sand.

Before discussing possible methods of control under each of these circumstances, the nature of oil reservoirs and the fluids therein will be reviewed. In all sand fields, the permeability of the sand varies widely, generally being in the range below 10,000 millidarcys,[14] and ordinarily averaging less than 1,000 millidarcys. Sands are generally less permeable across bedding planes than along the bedding planes. Abrupt changes in permeability occur across the bedding, but along the bedding the permeability changes are more gradual. The generation and accumulation of oil and gas occurred in the presence of water, and, although there is a tendency for the various fluid phases to separate into layers according to the density of the phases (gas above, oil between, water below), such separation is incomplete; therefore water is found in both the gas and the oil zones.[15,16,17] Furthermore, it is

[14] "Standard Procedure for Determining Permeability of Porous Media, Amer. Petrol. Inst. Code No. 27," *Drilling and Production Practice, 1935* (Amer. Petrol. Inst.), p. 267.

[15] H. C. Pyle and P. H. Jones, "Quantitative Determination of Connate Water in Oil Sands," *Drilling and Production Practice, 1936* (Amer. Petrol. Inst.), p. 171.

[16] O. L. Brace, "Factors Governing Estimation of Oil Reserves in Sand Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), p. 343.

[17] R. J. Schilthuis, "Connate Water in Oil and Gas Sands," *Petrol. Technol.*, Vol. 1, No. 1 (February, 1938), *Tech. Paper 869*.

probable that free gas may be found in a part of the oil zone or that oil may be present in the gas or water zones. The concentration of each phase is governed (1) by the differences in density between the phases, and (2) by capillary effects,[18] which depend on the structure of the rock and the interfacial forces between the rock, water, gas, and oil.[19] Little is known about these interfacial forces, yet they probably govern the processes of recovering oil to as great an extent as any other single factor.

CONTROL OF GAS

The fact that always two, and generally three, fluid phases are present in oil sands greatly complicates the mechanics of flow to wells. In spite of the complexity of the problem, sufficient work has been done to give some insight into the behavior of two-phase fluids flowing through sands. Wyckoff and Botset[20] have studied the flow of carbon dioxide and water through sands, and other work indicates the general applicability of the principles developed in their work to the flow of other liquids and gases.[21] The work of Wyckoff and his collaborators leads to the following conclusions.[22]

1. The permeability of the sand to either liquid or gas is reduced by the presence of the other phase.

2. The quantity of liquid and gas in the pore spaces of the sand determines the permeability to both liquid and gas, thus fixing the ratio at which liquid and gas flow through the sand.

3. At liquid saturations less than approximately 15 per cent, the permeability of the sand to gas is nearly equal to the permeability to gas that would exist if no liquid at all were present.

4. Small quantities of free gas tend to accumulate in the sand until a definite gas saturation is reached. At higher gas saturations, the gas flows with the liquid. The gas saturation below which gas accumulates in the sand has been called by Wyckoff "equilibrium saturation."

5. The gas-liquid ratio rises rapidly as the gas saturation increases beyond the value of equilibrium saturation.

[18] A. D. Garrison, "Selective Wetting of Reservoir Rocks and Its Relation to Oil Production," *Drilling and Production Practice, 1935* (Amer. Petrol. Inst.), p. 130.

[19] F. E. Bartell and O. H. Greager, "Relation of Adhesion Tension to Liquid Adsorption," *Jour. Ind. Eng. Chem.*, Vol. 21 (1929), p. 1248.

[20] Wyckoff and Botset, "Flow of Gas-Liquid Mixtures Through Unconsolidated Sands," *Physics*, Vol. 7, No. 9 (1936), p. 325.

[21] L. S. Reid and B. L. Huntington, "Flow of Oil-Gas Mixtures Through Unconsolidated Sand," *Petrol. Technol.*, Vol. 1, No. 1 (February, 1938), *Tech. Paper 873*.

[22] M. Muskat, R. D. Wyckoff, H. G. Botset, and M. W. Meres, "Flow of Gas-Liquid Mixtures Through Sands," *Petroleum Development and Technology, 1937* (Amer. Inst. Min. Met. Eng.), p. 69.

The data of Wyckoff and Botset have been studied critically by Muskat and Meres;[23] a fair picture may be obtained of the depletion of a reservoir in which only oil and dissolved gas are present and in which gravity drainage is unimportant. At the start, the lowering of pressure at the wells causes oil with its dissolved gas to move to the wells. The pressure in the reservoir is lowered as the oil and gas are produced and, as the pressure is lowered, dissolved gas escapes from solution. The gas escaping from solution is retained in the sand until the "equilibrium saturation" has been reached, after which free gas begins to flow with the oil and enter the well. Further decrease in oil saturation and increase in gas saturation causes a great increase in gas-oil ratio, and in turn a more rapid reduction in pressure. Upon exhaustion of the gas, there is no pressure, hence no pressure gradient under which the oil may flow to wells. The oil remaining in the sand is immobile, and will not be recovered unless the pressure on the field is restored. This type of production leads to recoveries of approximately 25–35 per cent of the oil in the reservoir; the recovery is independent of well spacing; and, unless the forces of gravity are brought into play, no permanent and effective control can be exercised over the gas-oil ratio.

For wells producing from the reservoir in which only oil and dissolved gas are involved and in which gravity drainage is unimportant, there is often a relationship between production rate and gas-oil ratio which sometimes seems to indicate that gas-oil ratio, hence recovery, can be controlled by regulating the production rate of the well. The sand in the neighborhood of a producing well is the first to yield its oil to the well; as time goes on, the more remote parts of the sand are drained. It can be shown that the effective drainage radius of the well increases approximately as the square root of the time the well has been produced,[23,24] and does not depend on the rate of flow. However, the degree of depletion of the sand within the drainage area does depend on the rate of flow. The higher the rate of flow, the less is the oil saturation in the vicinity of the well, and this condition tends to bring about a higher gas-oil ratio. On the other hand, the higher the rate of flow, the lower is the pressure; hence, the greater is the specific volume of the gas in the vicinity of the well. This condition tends to reduce the produced gas-oil ratio. These two opposing tendencies cause variations in gas-oil ratio with rate of flow on short-time tests, and often indicate that at a certain rate of flow a minimum gas-

[23] M. Muskat and M. W. Meres, "Flow of Heterogeneous Fluids Through Porous Media," *Physics*, Vol. 7, No. 9 (1936), p. 346.

[24] T. V. Moore, R. J. Schilthuis, and W. Hurst, "The Determination of Permeability from Field Data," *Proc. Amer. Petrol. Inst.* (1933), Sec. 4, p. 4.

oil ratio prevails. However, the factors which tend to cause the low gas-oil ratio are of a transient nature, and in the course of a long period of time the residual oil saturation throughout the reservoir tends to equalize, eliminating and probably reversing the conditions that may contribute to low gas-oil ratio at the start of flow. It appears, therefore, that production of wells at the rate required to establish minimum gas-oil ratio is not necessarily the key to maximum recovery from the gas-drive field, although there may be some advantages to the intermittent production of wells at that rate.

In the presence of a gas cap, the problem of production is more difficult. If gas is withdrawn from a gas cap at a greater relative rate than oil is withdrawn from the oil zone, the expulsion of dissolved gas from the oil will drive oil into the gas zone, reducing the oil saturation in the oil zone without producing any oil, thus hastening the exhaustion of the gas in the reservoir. On the other hand, if the gas can be retained in the gas cap, the expansive power of the gas cap as the pressure declines will tend to concentrate the oil in the oil zone. The oil zone contracts, but its oil saturation is maintained at a higher value; hence production can be secured from the remaining oil zone with lower gas-oil ratios.

Two general methods may be employed to reduce gas-oil ratios caused by the flow of gas, in mass, to a well, thus retaining the gas in the gas cap of a field: (1) production through tubing set properly with relation to the producing sand; (2) mechanical means for excluding the free gas.

The theory of the first of these methods has been presented by Muskat.[25] Its operation depends on setting tubing near the bottom of a relatively thick oil zone, and depends on gravitational drainage of the oil to the well. If the rate of oil flow is low enough so that the pressure differential opposite the tubing is less than the hydrostatic head of oil between the bottom of the tubing and the level of the gas-oil contact, a liquid seal may be maintained around the tubing, preventing entrance of any free gas. Ordinarily this rate is too low; and at higher rates, free gas is produced, but always in smaller quantity than if the tubing were absent or set above the gas-oil contact. Appreciable reduction in gas-oil ratio by the use of tubing can be obtained only in cases where there is a thick oil zone of high permeability.

Mechanical methods for excluding free gas include such common operations as setting casing or blank liner through a free gas zone, the use of packers,[26] and, more recently, the methods of squeeze

[25] M. Muskat, *The Flow of Homogeneous Fluids Through Porous Media*, McGraw-Hill Book Company, New York, pp. 696 *et seq.*

[26] R. J. Sullivan, "Gas-Oil Ratio Control in Flowing Wells," *Oil Weekly*, Vol. 87, No. 11 (November 22, 1937), p. 27.

cementing[27] that have been useful in the control of water. These methods are particularly successful in sands wherein the permeability in a vertical direction is less than that in a horizontal direction, or where impermeable or slightly permeable beds hinder the vertical movement of oil and gas. In this type of sand, short packers set close to the gas-oil contact are satisfactory. If, however, the sand be more uniform, the packers, to be effective, must be set a substantial distance below the gas-oil contact. Squeeze cementing is effective in many sands with free vertical movement, inasmuch as the cement forced back into the formation probably forms impermeable barriers to vertical movement in the neighborhood of the well, thus suppressing the tendency of the free gas to cone into the well.

Since it is desirable to maintain a free gas cap, it is equally desirable, when possible, to bring about the formation of a gas cap, or enlargement of an existing gas cap, from gas which escapes from solution in the oil on reduction in pressure. This may be brought about in some wells by production at sufficiently low rates of flow. Gas bubbles, when formed in the sand, tend to migrate upward to the top of the sand under the influence of gravity, and at the same time tend to move toward the well under the influence of the hydraulic gradient. These two factors are important in fixing the path of a gas bubble through the sand. It has been shown[28] that the hydraulic gradient varies in direct proportion to the rate of flow and in inverse proportion to the distance from the center of the well. Therefore, there is probably a zone near a well in which gas moves to the well, and beyond which gas accumulates at the top of the sand and then migrates to the high parts of the structure to form a gas cap. Thus a segregation of gas and oil may be brought about, and the oil concentrated in the lower zones of the sand and produced therefrom with low ratios. By bringing about segregation of the oil and gas, and by periodic repair of wells to shut off the flow of free gas, it is possible to increase recovery with a low average gas-oil ratio throughout the life of a gas-drive field.

Two other factors are important in this type of production. The existence of beds of widely varying permeability influences the mechanism of production. The tendency is for the most permeable beds to be drained most rapidly, resulting in a greater reduction in pressure in these than in the less permeable beds. As production is withdrawn, the tendency to drain the less permeable beds increases, because the

[27] I. W. Alcorn and J. U. Teague, "Bottom Hole Well Completions in the Gulf Coast," presented before Southwestern District, Amer. Petrol. Inst., April, 1937.

[28] H. D. Wilde, Jr., and T. V. Moore, "Hydrodynamics of Reservoir Drainage and Its Relation to Well Spacing," *Proc. Amer. Petrol. Inst.*, Thirteenth Annual Meeting (1932), p. 83.

pressure differential between the less permeable sand and the well increases relative to the pressure gradient in more permeable beds, also because a pressure differential exists which tends to cause movement of oil across the bedding planes from the less permeable beds to the more permeable beds through which the oil may flow more easily to the well. The varying permeability of the sand may also result in the localization of gas caps in the more permeable beds, and the intrusion of free gas into wells through lower or intermediate sands. Of course, this increases the difficulty of shutting off the gas by mechanical methods.

Another important consideration is the effect of dissolved gas upon the physical properties of the oil. Release of dissolved gas brings about an increase in the viscosity and surface tension of the oil,[29,30] effects which render the movement of oil to the well and the segregation of the oil and gas into separate zones more difficult.

CONTROL OF WATER

In most fields, the control of water is fully as important as the control of gas. The fundamental problem in water control is similar to that previously discussed in connection with gas, that is, to allow the water to displace oil, but to keep the intruding water and the remaining oil segregated, in order to maintain a high oil saturation in the oil zone in the vicinity of the wells, and to keep the water saturation so low that water will not flow into the wells.

A desirable objective in producing a water-drive field is to maintain the contact zone between oil and water in a smooth, and preferably a plane, surface. Because of the stratification of the sand into beds of widely varying permeability, this can only be accomplished if the average velocity of displacement of oil by water is nearly independent of permeability. The velocity with which water displaces oil depends on the following important forces.

1. Frictional forces, which depend on the permeability of the sand, the viscosity of the fluids flowing, and the rate of flow. These forces tend to bring about more rapid movement in the more permeable sands. However, their magnitude is proportional to the rate of flow; therefore, the frictional forces are subject to control by varying the rate of flow.

2. Capillary forces, which depend on the composition of the fluids in the sand, the nature of the sand surface, and the size and arrange-

[29] W. N. Lacey, "Practical Benefits of Pressure Maintenance in Petroleum Production," *ibid.*, p. 16.

[30] D. T. Jones, "Determination of Surface Tension and Specific Gravity of Crude Oil Under Reservoir Conditions," *Petroleum Development and Technology, 1936* (Amer. Inst. Min. Met. Eng.), p. 81.

ment of the pores. The magnitude of capillary forces depends, therefore, on permeability[21] and, other things being equal, is greater in the less permeable sands. In most cases, the displacement pressure of the capillary forces tends to drive water into the oil zones more rapidly in the less permeable sands. Capillary forces are not subject to direct control.

3. Gravitational forces, which depend on the difference in density between the oil and water, and on the extent to which the contact zone between oil and water has been moved out of the equilibrium position of a level plane.

Qualitatively, these three forces act as follows: frictional forces tend to cause more rapid advance of water in the more permeable sands; capillary forces less rapid advance in the more permeable sands; and gravitational forces tend to equalize the water encroachment. To obtain substantially uniform advance of water, the frictional and capillary forces must be approximately in balance. At first glance, it appears that capillary forces are so small that they would have little effect on the mechanism of water encroachment at ordinary rates of flow. However, a closer inspection of the problem will show that these small forces may be important in view of the complex nature of the system in which they act.

Consider the conditions prevailing in an oil reservoir under water drive prior to production. A series of oil-bearing sand strata of widely varying permeability is exposed to the wells, and is in communication with the water zone at a point lower on the structure. As the oil is withdrawn, the drainage radius of the well increases, approximately as the square root of the product of time and the permeability of the sand,[23,24] thus causing a tendency toward unequal growth of the drainage area in adjacent sand beds of different permeability. The result is that the pressure in beds of low permeability is higher than in beds of high permeability, and if there is any communication between the beds of sand, drainage of oil occurs to the permeable beds from less permeable beds. Ordinarily, the resistance to flow is much higher across bedding planes than along bedding planes, not only because the permeability is less, in the single bed of sand, to flowage across the bedding planes, but also because flow across a series of sands of varying permeability is limited to a great extent by the least permeable bed in the series. Nevertheless, the area through which drainage across bedding planes may occur is so large that great quantities of oil may be transferred into the more permeable beds. This action has a marked effect on pressure gradients, especially in regions remote from the wells, the tendency being to reduce the pressure

[21] Bartell and Osterhof, "Pore Size of Compressed Carbon and Silica Membranes," *Univ. Michigan* (Ann Arbor).

gradients in the more permeable sands below the value that would have prevailed in the absence of drainage from adjacent beds of lower permeability. By this mechanism, the effect of frictional forces is reduced in the more permeable sands and magnified in the less permeable sands. Capillary forces then have a better chance to operate effectively, and under favorable conditions may bring about a balance between frictional and capillary forces which will maintain a reasonably uniform encroachment of water. The uniformity of the encroachment depends primarily on the rate of flow, and if the rate becomes so high that the magnitude of the frictional forces becomes large in comparison with the magnitude of the combined capillary and gravitational forces, irregular encroachment will result.

The physical properties of the oil are highly important in determining the regularity of water encroachment. Frictional forces are proportional to viscosity, which increases as gas is released from solution due to a reduction in pressure.[29] Capillary forces are proportional to the interfacial tension between the oil and water. No published data are available on the effect of dissolved gas on interfacial tension, but there is some evidence to indicate that it decreases with release of pressure. Since a low viscosity and high interfacial tension are desirable, the maintenance of reservoir pressure will result in a more uniform advance of water.

In water-drive fields, well spacing has no effect on ultimate recovery, but such wells as are drilled should be located judiciously in order to obtain full benefit from the water drive. An advancing water front has some tendency to finger in to single wells or to areas in which oil is being withdrawn at a rate greater than in surrounding areas.[32] After the water reaches the well, production can be maintained only by producing excessive quantities of water. Wells located at the greatest distance from the water-oil contact zone can therefore produce the greatest amount of oil. If the production rate be slow enough, a few wells so located will produce all of the recoverable oil in the field. However, to maintain a satisfactory production rate from the field without bringing about too high velocity and too low pressure at the wells, it may be necessary to drill wells throughout the field, the number depending on the rate of production which is to be maintained.

Gravitational forces are especially important in some phases of water control, particularly in the problem of preventing coning of water. This has been studied by Wyckoff and Muskat.[33] In a homogene-

[32] R. D. Wyckoff, H. G. Botset, and M. Muskat, "The Mechanics of Porous Flow Applied to Water Flooding Networks," *Petroleum Development and Technology, 1933* (Amer. Inst. Min. Met. Eng.), p. 219.

[33] M. Muskat and R. D. Wyckoff, "An Approximate Theory of Water Coning," *ibid., 1935*, p. 144.

ous sand, the reduced pressure at the bore of the well tends to cause movement of water which may underlie the oil into the well. At low rates of flow, the surface between the oil and water will become distorted in such a manner that the difference in hydrostatic head between the oil and water balances the hydraulic gradient under which oil flows to the well. A stable water cone is thus formed beneath the well which does not reach to the well bore; hence, no water enters the well. If, however, the rate of flow be increased beyond a certain value, the hydraulic gradient becomes too great to permit the hydrostatic forces to maintain a stable cone, whereupon water enters the well. The presence of impermeable or slightly permeable beds between the well and the water-oil interface has a marked tendency to reduce or eliminate the coning effect and thus to permit greater rates of flow without danger of drawing water into the well in this manner. It is believed that because of the wide variations in permeability encountered in most fields, coning, as described herein, is not a serious consideration in most wells at ordinary rates of flow. In those places where it is an important factor, it can be reduced by plugging back, preferably by the squeeze method, which interposes an impermeable disc of cement between the well and the water.

There is at least one other mechanism by which wells produce water, namely, the production of connate water from the oil sand. This problem has been studied by Dunlap,[34] who showed that oil can move through sands containing a substantial amount of water without bringing about movement of the water. However, at water saturations in excess of certain values which depend on the oil velocity, the water flows with the oil. In the early stages of production, most of the oil is produced from the most permeable beds of sand, which ordinarily are those containing the least water.[17] Later, a greater proportion of the oil is produced from sands of lower permeability, bringing about higher velocities in these sands which, because they contain higher percentages of water, may produce water with the oil.

Proper completion of wells is one of the most important phases of water control, and in proper completion the important factors are: (1) depth of penetration into the producing sand, and (2) amount of sand to take in. The answer to the problem depends almost entirely on the structure of the sand. In a fairly homogeneous sand, in which vertical movement of the oil can readily occur, the entire productive section may be drained by a single completion. In such a sand the bottom of the well may be a substantial distance above the water-oil

[34] E. N. Dunlap, "Influence of Connate Water on the Permeability of Sands to Oil," *Petrol. Technol.*, Vol. 1, No. 1 (February, 1938), *Tech. Paper 874*.

contact in order to prevent coning, as it is not particularly important to expose the entire section to the well. In the more common case of a sand made up of comparatively thin strata of widely varying permeability, there is far less danger of water coning, and the well may safely be completed nearer the water level. In this type of sand, irregular water encroachment is more likely to occur by channeling through the permeable streaks of sand, and it is common for these streaks to be in the upper or intermediate part of the sand. The location of water-bearing strata and the plugging off of such strata without also plugging any oil-producing sands below is a complicated and expensive operation and should be avoided if possible. Probably the best technique with which to produce a sand body having highly irregular permeability is to complete wells to take in only a relatively thin section of sand, producing this section to exhaustion, later reworking the well to plug off the exhausted section and then to open a fresh section. This practice is being followed in some fields, and although no data are available, theoretical considerations indicate that it should result in a greater ultimate recovery of oil.

In all water-drive fields and many gas-drive fields, wells eventually will produce water, and it is generally advisable to attempt to plug off such water. The production of water is expensive, water disposal is generally a serious problem, and the production of excessive quantities of water results in a loss in ultimate recovery. In some wells, where thick productive zones occur, attempts are made to determine the position at which the water enters and to block off the water-producing section, leaving oil-producing sections above and below.[35] The methods used are not entirely satisfactory for all places, and where thin producing zones are encountered, it is generally the practice to cement off the entire section below the water-producing zone by common "plug" or "squeeze" methods.[36,37]

A number of chemical methods have been proposed for the selective shut-off of water sands, for example, the use of silicon tetrachloride,[38] which will precipitate an impervious silica gel on contact with water, but which is not affected by hydrocarbon oils. However, none of these processes has proved commercially successful.

[35] W. C. Whaley, "Reconditioning Oil Wells in California," *Proc. Amer. Petrol. Inst.*, Fourteenth Annual Meeting (1933), Sec. IV, p. 103.

[36] R. E. Watson, "Cementing Methods for Excluding Water from Producing Wells," *Drilling and Production Practice, 1934* (Amer. Petrol. Inst., 1935), p. 8.

[37] C. P. Parsons, "Plugback Cementing Methods," *Petroleum Development and Technology, 1936* (Amer. Inst. Min. Met. Eng.), p. 187.

[38] H. T. Kennedy, "Chemical Methods of Shutting Off Water in Oil and Gas Wells," *ibid.*, p. 177.

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FIRST GEOLOGIC WORK FOSTERED BY UNITED STATES GOVERNMENT[1]

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The earliest geological activities of our Government will no doubt be of interest to many persons because of the marked contrast to the modest beginning a century ago with the splendid achievements of modern geologists in broadening the science and in pointing the way to development of vast wealth in minerals. This early history of the Acts of Congress appropriating funds for geological work came to the attention of the writer some time ago when inquiry was made of the director of the United States Geological Survey regarding the disposal of the following described appropriation.

By the act of June 28, 1834, the sum of $5,000 was appropriated to be applied to geological and mineralogical survey and researches.

A search of old records in the Library of Congress, and in the War Department in Washington revealed the following circumstances.

The first specific appropriation act referred to, entitled

An act making additional appropriations for certain harbors and removing obstructions in the mouths of certain rivers, for the year one thousand eight hundred thirty-four (Twenty-third Congress, Session I, Chapter 103, 1834, United States Statutes at Large, Volume 4, page 703, 704),

reads in part as follows:

. . . and for defraying the expense of surveys pursuant to the act of the thirtieth of April, eighteen hundred and twenty-four, including arrearages for eighteen hundred and thirty-three, twenty nine thousand dollars, of which sum five thousand dollars shall be appropriated and applied to geological and mineralogical survey and researches.

The Act of April 30, 1824 (Eighteenth Congress, Session I, Chapter 46, United States Statutes at Large, Volume 4, 1824–1835, pages 22, 23), referred to, entitled, "An act to procure the necessary surveys, plans, and estimates upon the subject of roads and canals," authorized the President to cause the necessary surveys, plans, and estimates to be made for routes of such roads and canals as he might deem of national importance in a commercial or military point of view, or necessary for the transportation of the public mail, such surveys, plans and estimates to be laid before Congress. The act authorized the President to employ two or more skillful civil engineers and other

[1] Published by permission of the director, United States Geological Survey.

[2] Formerly a member of the United States Geological Survey.

officers of the corps of engineers in carrying out this work and appropriated $30,000 for the work.

So much for the law relating to the first geological survey work for which funds were appropriated by Congress. Some of the prior history leading up to this first congressional appropriation for such work shows how the geological activities of the Government were destined to develop from a scion of the engineering and topographic work of the War Department.

It appears that George William Featherstonhaugh of Philadelphia had for a long time prior to 1833 directed his attention to the mineral resources of the Union with a view to the preparation of a geological map of "the whole country," and that in order to disseminate information regarding his work he edited and published in Philadelphia a *Geological Journal*, the expenses of which exceeded the receipts. Confident that there was a great field for this valuable work, he made application to Congress to provide for the execution of the geological investigations, including the collection of materials for the construction of a geological map of the United States, and for financial aid for his *Geological Journal*. Senate Document 35, January 18, 1933 (Twenty-second Congress, 2nd Session), which was a "Report from the Secretary of War in compliance with a resolution of the Senate on the Memorial of George W. Featherstonhaugh," was accompanied by a letter of Featherstonhaugh explaining in detail his plan for making a geological map

> exhibiting the mineral formations, the metallic beds, the geological structure of chains of hills and their continuity and elevation, together with all the facts both topographic and general which can illustrate the mineral riches of our country, their quality, quantity, and the facility of procuring them.

It was intended by geologist Featherstonhaugh that his work should be the means of laying the broadest foundation for the systematic study of the principles of modern geology among the officers in the United States service. His conception was that the practical part of geology may be connected in a most useful and economical manner with military engineering. He stated in his letter accompanying the report that he had been compelled to suspend publication of the *Geological Journal*. Whether Congress was easily touched by this request to aid financially a scientific publication was not directly disclosed by the records. However, it did not take Congress long to act, as the employment of a "suitable person in aid of the Topographical Bureau, to ascertain the mineralogy and geology of each of the several states of the Union, with a view to the construction of a mineralogical and geological map of the whole territory of the United States," was

the subject of the Report of the Committee on Military Affairs of February 21, 1833, No. 106, Twenty-second Congress, 2nd Session. This agitation appears to have led to the establishment of the professorship in geology and mineralogy in the Military Academy at West Point, with a view to training the graduates to make "a geological chart" of the various districts to which they might be assigned.

The Committee on Military Affairs was of the opinion that the mineralogic and geologic work which was the subject of their Report No. 106, of February 21, 1833, could be "effectually done without any increase of the annual appropriation under the Act of April 30, 1824, and by simply adding this important object to the duties of the Topographical Bureau," and recommended that the chairman of the Committee on Ways and Means be requested to amend the bill, "making the appropriation on this subject so as to give the power to embrace this subject." Accordingly the Act of March 2, 1833 (Twenty-second Congress, Session II, Chapter 69, United States Statutes at Large, Volume 4, page 649), provided "For defraying the expenses incidental to making examinations and surveys under the act of the thirtieth of April, one thousand eight hundred and twenty-four, twenty-five thousand dollars."

Geological and mineralogical investigations were therefore aided by Congress through the Topographical Bureau of the War Department prior to the first specific appropriation by the act of June 28, 1834. By virtue of the latter act, geologist George William Featherstonhaugh was employed under instructions of Lieutenant Colonel J. J. Abert, United States Topographical Engineers, dated July 12, 1834,

> to repair to some point on the northern boundary of the Territory of Arkansas and personally inspect the mineral and geological character of the highlands and watersheds where the public lands are situated, of that elevated country lying between the Missouri and Red Rivers, known under the designation of the Ozark Mountains.

His instructions also stated that:

> Although, by these instructions, your investigations are limited to the Territory of Arkansas and the adjacent public lands, it is nevertheless desirable that, in the report to be made by you on your return to this city, whatever geological information you may possess, which can be usefully applied to the illustration of the investigations you are about to make, and which may aid in developing the resources of the countries you are directed to examine, and their geological connection elsewhere, should be fully stated for the information of the Government.

Featherstonhaugh was then 54 years old.

After a field trip of 6 months he returned to Washington on January 31, 1835, having covered a distance of 4,600 miles, of which more than 3,000 were traveled by land. His report was called for by the House of Representatives on February 14, 1835. The report which was transmitted to Congress on February 17, 1835, by the Secretary of War, is titled "Geological Report on an examination made in 1834 of the Elevated Country between the Missouri and Red Rivers." It was printed by order of the House of Representatives and the Senate and was published as House Document No. 151, Twenty-third Congress, second Session, and as Senate Document No. 153, same session.

The book of about 100 pages contains a geologic and mineralogic report on the area covered and a geologic section from the New Jersey coast across the country to the Red River in Texas.

The records did not disclose what part of the $5,000 appropriation was used for this exploration or whether part of the fund was devoted to other work, but it is likely that the salary of the geologist and six months work over such a large area required most, if not all, of this amount. It seems, from one of the provisions of the Act of March 3, 1835 (Twenty-third Congress, Session II, Chapter 30, United States Statutes at Large, Volume 4, 1824–1835, page 769), that a separate appropriation was made for payment of documents printed by Gales and Seaton, who published the Featherstonhaugh report, and it is probable that payment for the printing of this report by them was provided in a separate appropriation, because the provision immediately following in this act reads as follows.

> For payment for printing the documents relating to the public lands and for binding, and for engraving the necessary maps ordered to be printed by the Senate, ten thousand eight hundred and sixty dollars.

The General Account of Receipts and Expenditures of the United States for the year 1834, published in 1835, page 106, contains under "Surveys and Estimates, Roads and Canals," an item: "G. W. Featherstonhaugh, Geologist, $1,300." In the same Volume, in the accounts for 1835, under Surveys and Estimates, Roads and Canals, appears an item of $2,749.56 paid to G. W. Featherstonhaugh.

During 1835 Featherstonhaugh made another exploratory trip. His report is titled "Report of a Geological Reconnaissance made in 1835 from the Seat of Government by the way of Green Bay and the Wisconsin Territory to the Coteau de Prairie, an elevated ridge dividing the Missouri from the St. Peter's River," and was printed by Gales and Seaton, 1836 (Senate Document 333, Twenty-fourth Congress, First Session).

It appears that the continuation of geological exploratory work was paid for from the regular appropriation to the Topographical Bureau, as the Act of January 27, 1835 (Twenty-third Congress, Session II, Chapter 4, United States Statutes at Large, Volume 4, page 747), provided for "allowances to officers on topographical duty, $53,000."

The organization and increase of a corps of topographical engineers and the filling of vacancies from the personnel of the army and from the civil engineers employed under the act of April 30, 1824 (Chapter 46), previously referred to were provided for by Section 4 of the act of July 5, 1838 (Twenty-fifth Congress, Session II, Chapter 162, United States Statutes at Large, Volume 5, 1836–1845, page 256–260), entitled "An act to increase the present military establishment of the United States, and for other purposes." This act also repealed the authority of the President granted, April 30, 1824, to employ such civil engineers in the future.

An additional professor "to instruct in the studies of chemistry, mineralogy, and geology," with an assistant professor, probably for the military academy at West Point, was also provided for by Section 19 of the act of July 5, 1838.

George William Featherstonhaugh, the first geologist of the United States Government, was born 158 years ago, in 1780. He was 19 years old when George Washington died; 54 years old when first employed as Government geologist in 1834 and 86 years old at his demise in 1866. It is natural to imagine what the situation might have been without the appeal to Congress by Featherstonhaugh. His lack of a paying list of subscribers to his *Geological Journal* may have aided in hastening the initiation and development of geological work by the Government. Had it not been for his efforts possibly no similar influence would have been exerted on the War Department and Congress until many years later. Featherstonhaugh deserves considerable credit for starting something distinctly worth while.

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PROBLEM OF SECONDARY TILT—HARKER'S SOLUTION CORRECTED[1]

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ABSTRACT

Harker's solution for the problem of secondary tilt is shown to be invalid for most cases. The nature of the method is explained and a modification is offered which will give accurate results. Another method, based on the use of cotangents instead of tangents, is described.

The problem of the secondary tilt—the determination of the resulting dip when any initially inclined plane is rotated anew in a direction different from the first, or the reverse—is likely to give the non-mathematical geologist some trouble. The remarkably simple graphic figure proposed 54 years ago by Harker[3] and recently recommended to the attention of American geologists by Fisher[4] seems to afford an easy solution. For most cases, however, Harker's method is only an approximation, and for some combinations of dips it yields a notable error. It is the writer's purpose to point out the nature of the error and to offer a correction, as well as another graphic method.

In geologic work the method finds application chiefly in restoring beds under a tilted angular unconformity, or faults that have been rotated, to their original positions. Occasion to use it has apparently not been common, but it probably could be used to restore rotated faults, joints, and other planes more than it has, and merely as an element in the application of graphic mathematics to geologic structure the problem deserves attention. In any event as Harker's solution is presented without qualification in the works here cited and at least one other,[5] some notice of its insufficiency is in order.

For all the following demonstrations, a problem is selected of the general order presented by Fisher.[6]

Given a set of beds dipping southwest, overlain in angular unconformity by a set dipping southeast: to find the original dip of the underlying beds. Harker's solution is as follows (for illustration reference is made to Figure 2, of which the Harker construction is the

[1] Manuscript received, June 11, 1938.

[2] The Ohio State University.

[3] A. Harker, "Graphical Methods in Field Geology," *Geological Magazine*, Vol. 1 (3) (1884), pp. 154–62.

[4] D. J. Fisher, "Some Dip Problems," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 3 (March, 1937), pp. 340–50.

[5] Kenneth W. Earle, *Dip and Strike Problems* (London, 1934), pp. 116–17.

[6] D. J. Fisher, *op. cit.*, p. 349.

groundwork). To a suitable scale draw OA equal to the tangent of the dip of the lower beds, in the direction of dip, thus making it a tangent vector. The simplest way of doing this is by means of a tangent protractor as described by Harker.[7] Draw AC' in the direction in which the beds are to be rotated, that is, opposite to the direction of dip of the upper beds. From O drop OD perpendicular to AC', and extend so that DD' is unity on the scale chosen for plotting. Draw AD' and

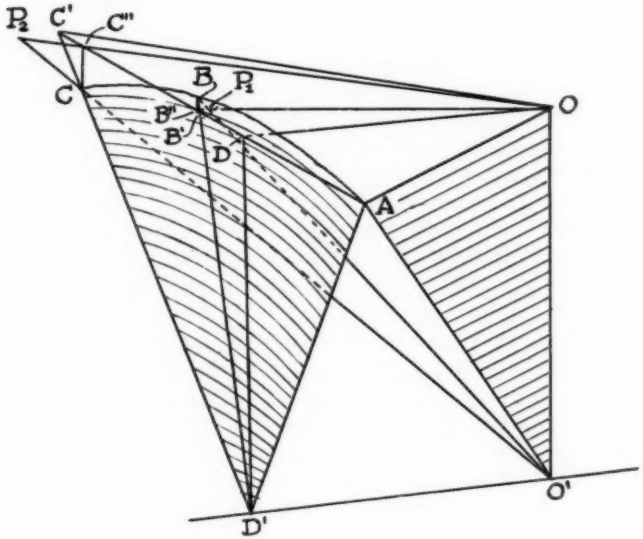

FIG. 1.—Three-dimensional drawing showing basis of Harker method.

turn off the angle $AD'C'$ equal to the amount of rotation (dip of the upper beds). Draw OC', which, according to Harker, is the tangent vector of the required dip.

In order to make clear the nature of the error in this construction Figure 1 has been prepared—a perspective drawing of the lines and planes concerned in their three-dimensional relations. For the demonstration of the principle involved precise quantities are not necessary, and Figure 1 merely represents a situation of the order given by Fisher, as previously specified, with the exception that two angles of secondary rotation are shown, approximately 30° and 55°, to make clear two different cases. It is desired to rotate the upper beds to

[7] A. Harker, *op. cit.*

horizontality and determine the dip of the lower beds under that condition, namely, their original dip. The problem is solved by the use of two horizontal reference planes, an arbitrarily chosen unit distance apart, O lying in the upper and O' in the lower. O' is also in the plane of dip below the unconformity, and $O'A$ is the normal to this plane, A being the piercing point of the line in the upper plane; OA is therefore the tangent vector of the angle of dip of the lower beds. Now, the strata are to be rotated in the direction AC', opposite to the direction of dip of the upper beds, and OD, normal to AC', is the strike of the secondary movement. Let D' be in the lower reference plane directly beneath D; then $D'O'$ is the axis of rotation. As the beds are turned on this axis, A will follow the arc ABC, and $O'A$ will remain, of course, perpendicular to the plane that is being rotated. Suppose the rotation stops when A reaches B, the angle $AD'B$ (about 30°) being the amount of secondary tilt, and $D'B$ cutting AC' at B; it is evident that $O'B$ is the normal to the plane in its new position, and not $O'B'$, as assumed by Harker, who merely folded plane $AD'B'$ along AB' into the horizontal position to get his construction. The true tangent vector required, therefore, is not OB', but OP_1, P_1 being the piercing point of $O'B$ in the upper plane, determinable, as shown in the drawing, by dropping the perpendicular BB'' and joining B'' to O to get the projection on the upper plane of $O'B$; P_1 is then at the intersection of $O'B$ and OB''.

A second case, involving the larger angle of rotation $AD'C'$, is also shown on Figure 1, the nomenclature of points being homologous with that of the first case; here the true tangent vector of the required dip is OP_2 instead of OC' as in Harker's construction. It is apparent that Harker's method gives the correct result in one case only, namely, when the angle of secondary tilt happens to be just twice the angle $AD'D$. It is also evident that for angles of rotation near this value the error is slight, and there is a zone of tolerance in which the amount of error may lie within the limits of accuracy attainable in the field or desired in the result. For such cases Harker's construction will do well enough, but when the vertical triangle departs far from the isosceles condition the error is too great. The case chosen by Fisher[8] to illustrate Harker's method happens to fall within a reasonable zone of tolerance; the error is less than 1° in the strike and a little more than 1° in the dip, both amounts within the limits of accuracy in field data for most practical situations. Inspection of the figure drawn on Harker's specifications easily shows whether it is adequate.

If the Harker figure is not adequate, it may be corrected, as is

[8] D. J. Fisher, *op. cit.*

evident on Figure 1, by a few additional operations. Figure 2 is constructed to show the actual graphic procedure; it is based on the conditions set up by Fisher except that the dip of the upper strata and consequently the angle of rotation is set at 50°, in order to show a clear discrepancy from the result of Harker's method. The nomenclature of Figure 1 is retained. The procedure is as follows.

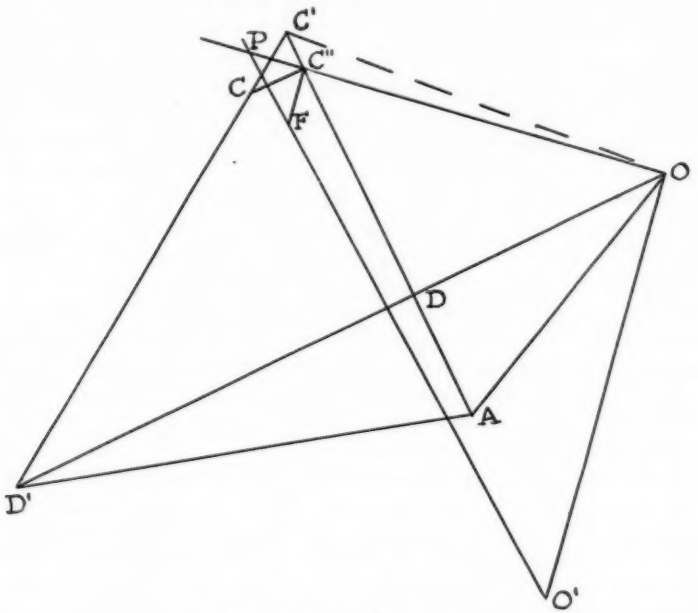

FIG. 2.—Harker's construction corrected.

Make the Harker construction $OAD'C'$. Lay off $D'C$ equal to $D'A$. Draw CC'' normal to DC'; then the true original dip will lie on the line through O and C''. Join these points, extending beyond C'' as shown. Erect the perpendicular $C''F$ equal to $C''C$. Draw OO' normal to OC'', OO' being unit distance. Then the line from O' through F will intersect OC'' extended at P, which is the piercing point in the upper plane of the normal to the dipping plane in its original position, and OP is the tangent vector of the original dip. The results are, strike N. 17° E., dip 44½° NW.; by the Harker method, strike N. 21° E., dip 42½°.

The reverse problem, namely, the determination of the resultant dip when an inclined plane is subjected to a second rotation, can be

worked out starting from Harker's construction in fashion similar to the foregoing.

Another method of solving the problem may be worked out by the use of cotangents instead of tangents. It is slightly more tedious than the tangent method, but for some combinations of angles it is easier to handle, and it provides a means of checking results obtained by the

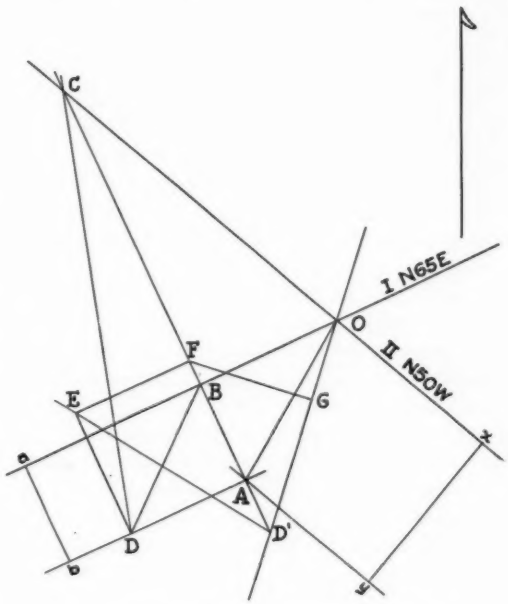

FIG. 3.—Solution of problem by cotangent method.

modified Harker method. As regards the visual element it is superior in that it develops the figures in their normal positions, whereas the lines of the tangent construction are at right angles to the planes involved, a situation more difficult to visualize.

Since it is impossible to give directions based on one example that will solve the problem for any combination of dips, it is perhaps well to explain first the principle of the method. Letter references are to Figure 3. As in the tangent method, two horizontal reference planes are used, a unit distance apart. Let the bedding of the upper strata be called plane I and that of the lower plane II. The traces of the two planes on the reference planes are drawn, and their intersection

(*OA*) projected on the upper plane. The component of dip of plane II in the direction *D'C*, at right angles to the strike line of plane I, is first determined; this component is then rotated, on the strike of plane I as an axis, through the dip angle of plane I, and in its new position it is the component of original dip of plane II in the direction *D'C*. The position, *OD'*, of the intersection between planes I and II when plane I is horizontal is obviously the original strike of plane II. With the strike and one component of dip known, the true dip is easily projected. The construction for the same problem as that of Figure 2 is given in Figure 3. The procedure is as follows.

Draw lines (I and II) representing the strikes of the two formations, intersecting at *O*. Draw lines parallel to the strike lines, distant in the direction of dip by amounts, *ab* and *xy*, equal to the cotangents of the dip angles, to a suitable scale. These lines intersect at *A*, and *OA* is the projection in the plane of the drawing of the intersection of the dipping planes. Drop the perpendicular *AB* and extend in both directions as shown. Lay off *AD* equal to unity; then the angle *ABD* is the dip of plane I and *ACD* is the component of dip, in this azimuth, of plane II, both folded along the line *AC* into the plane of the drawing. Lay off *BD'* equal to *BD*, and the angle *BD'E* equal to *BDC;* this is the component of dip of plane II in the direction *D'C* after plane I has been rotated to horizontality. Draw *D'O;* this is the original strike of plane II. Draw *DE* parallel to *AC* and drop *EF* perpendicular to *AC*. The perpendicular *FG* from *OD'* to *F* is then the cotangent of the original dip.

If it is desired to keep the entire construction on graphic basis, the cotangent values may be determined by constructing the requisite triangles. This procedure has the advantage of heightening the visual element, but it complicates the drawing.

Mertie[9] in 1922 proposed a solution to the problem, by means of spherical trigonometry, that is fairly simple. His equations may be preferred by the mathematically minded geologist, but many set a higher value on the visual perception of the lines and planes, in their three-dimensional relations, that is afforded by graphic methods founded on descriptive geometry, and such methods have the further value of guarding against gross error in the orientation of the resulting quantities.

The writer desires to acknowledge indebtedness to W. W. Rubey for general criticism of this paper, and in particular for modifications that simplify the cotangent figure.

[9] J. B. Mertie, "Analysis of Structure below an Unconformity," *Econ. Geology*, Vol. 17, No. 7 (1922), pp. 572–74.

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VOL. 22, NO. 9 (SEPTEMBER, 1938), PP. 1261-1271, 4 FIGS.

PROBLEM OF TWO TILTS AND THE STEREOGRAPHIC PROJECTION[1]

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ABSTRACT

Harker's solution of the problem of two tilts is shown to be erroneous for the general case. This problem may be worked rapidly and accurately in terms of the normals to the bedding planes by means of a tracing paper laid over a meridional stereographic net. In an appendix the meridional stereographic net is simply described and the same problem is worked in terms of the bedding planes themselves. It is believed that this discussion will furnish the trained geologist with a sufficient background to work nearly any problem involving lines and planes which can be considered to pass through the point of observation in the field. Such problems may involve bedding, fault, joint, or cleavage surfaces, which in many cases may usefully be regarded as planes for short distances; also lines or directions within these surfaces—such as slickensides, outcrop of beds or faults, elongation of minerals in cleavage surfaces, flow lines in flow layers—may be rotated from the direction of observation in the field into any desired plane. After a little practice such problems are more easily visualized by students when so handled than when descriptive geometry is used, and the solution is attained much more quickly and simply by these direct graphical methods.

In a recent paper[3] among other things the writer gave Harker's solution of the problem of two tilts. That is, where a plane, such as a bedding, joint, or fault surface, has suffered two tilts, its present direction and amount of dip can be measured, as can the direction and amount of the second tilt if these be represented by overlying dipping beds separated by an *angular* unconformity. The problem is to find the direction and amount of dip of the lower beds, etc. before the second tilt. As stated by Mertie,[4] Harker solved this problem "without proof or discussion," and at the Christmas meetings of the Geological Society of America at Washington, December, 1937, Professor Edmund M. Spieker[5] told the writer that Harker's solution was incorrect for the general case.

Harker's solution is based on the plotting in the gnomonic projection[6] of a point *A* (in Figure 4 of the writer's earlier paper), corresponding to a normal to the plane of the lower beds (dip 35° to S. 40° W.) then rotating this in the direction of updip of the upper series (N. 25° W.) through the angle of dip of the upper beds (30°), thus

[1] Manuscript received, June 9, 1938.

[2] University of Chicago.

[3] D. Jerome Fisher, "Some Dip Problems," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 3 (March, 1937), pp. 340–51. See the problem on the lower half of page 349.

[4] J. B. Mertie, Jr., "Analysis of Structure below an Unconformity," *Econ. Geol.*, Vol. 17 (1922), pp. 572–74.

[5] Edmund M. Spieker, "Problem of Two Tilts—Harker's Solution Corrected," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 9 (September, 1938), pp. 1255–60.

[6] See for example W. E. Ford, Dana's *Textbook of Mineralogy* (1932), pp. 56–60.

locating the point C, the pole of the lower beds before the second tilt; in short the whole is rotated to the position of horizontality for the upper beds. The axis of rotation is thus the strike line of the upper beds, and so the pole A representing the lower beds will move along a small circle on the sphere which in the gnomonic projection is an hyperbola[7] and not the straight line AC of Figure 4. Carried out graphically on the gnomonic net the answer to the particular problem given is 34° to S. 86° W. This is essentially the same as stated at the top of page 350. In short in this particular case Harker's solution is entirely satisfactory, but this is so only because the point z of Figure 4 is nearly midway between A and C.

Another example may be chosen to illustrate the fallacy of Harker's method in the general case, and also to point out a simple graphical mode of solution. *Given:* upper beds dip 30° to S. 25° E. and lower beds dip 56° to S. 12½° W.; Harker's solution gives an answer of 44° to S. 43° W. (z lies beyond C, going from A), whereas the true answer is 35½° to S. 35° W. The latter figure was obtained by means of the ordinary meridional stereographic net[8] (Fig. 1). This net is preferred because it is much better known than the gnomonic net, and moreover it covers cases where dips exceed 65°, the practical limit of the gnomonic net.

Fasten the net to a drawing board with four thumbtacks, and drive a needle in at the center of the net so that it projects ¼ inch or less above it.[9] Paste a small square of Scotch tape or glued cloth or manila paper in the center of a piece of tracing paper of diameter slightly larger than the net, and lay this on the net with the needle punching through the small square. Now draw four short radial lines on the tracing paper near the circumference of the net 90° apart, by tracing the ends of the two diameters of the net, and label them N, E, S, and W, as in Figure 3. Note the N and S poles of the net are where

[7] H. Hilton, "The Gnomonic Net," *Mineralogical Magazine*, Vol. 14 (1904), pp. 18–20. Also F. E. Wright, "The Methods of Petrographic-Microscopic Research," *Carnegie Inst. of Washington Pub. 158* (1911), Pl. 10.

[8] Commonly known as the Wulff net. C. S. Barrett (footnote, p. 35 of "The Stereographic Projection," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 124 (1937), pp. 29–58) lists many sources supplying such nets of several sizes; or write the Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pennsylvania. The E. Leitz Company sells meridional stereographic as well as Lambert meridional equal-area nets of 20-cm. diameter very conveniently mounted on an aluminum board with a rotatable ring which supports the tracing paper. The Lambert net is used in petrofabrics, but can also serve to solve problems such as those here described.

[9] A more satisfactory mount can be made by cementing the net to a disk of sheet aluminum. Staple to this through the center of the net a 1/50-inch thick sheet of transparent colorless cellulose acetate, so that it may be rotated easily. The upper surface of this plastic sheet should be mat, so that it readily takes pencil marks, which are easily erased.

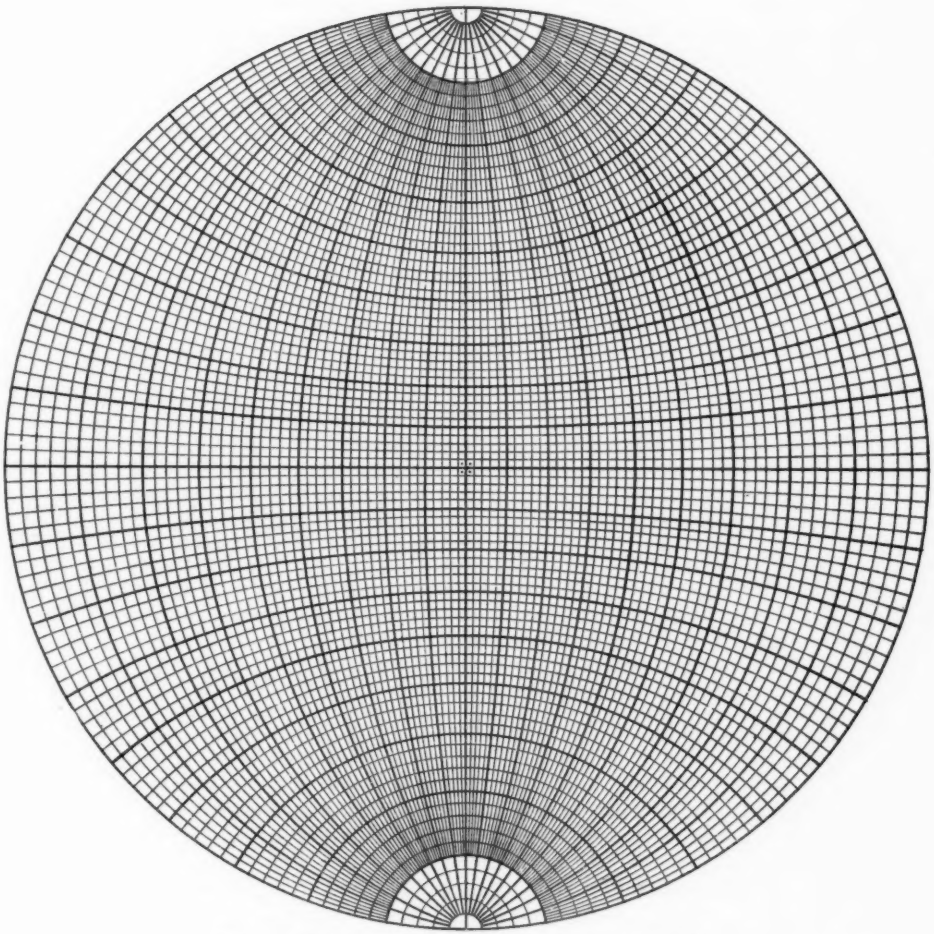

FIG. 1.—Meridional stereographic net drawn to 2° intervals.

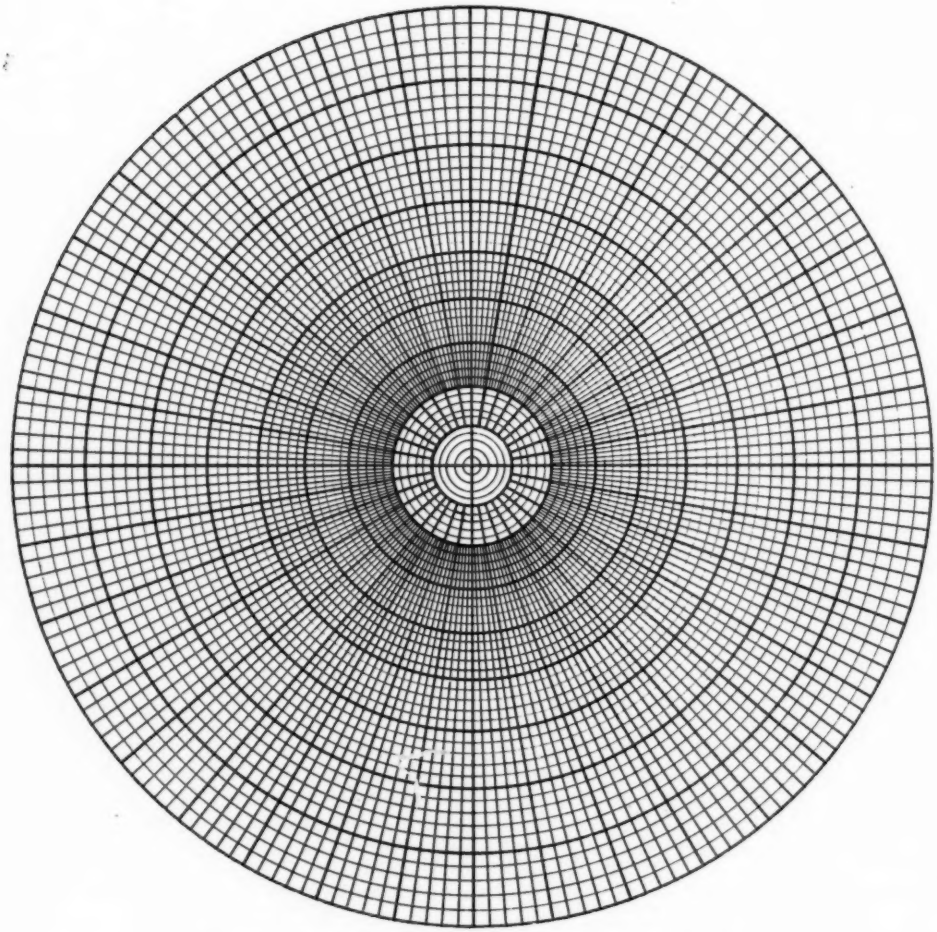

FIG. 2.—Polar (equatorial) stereographic net drawn to 2° intervals.

the outwardly convex circular arcs (representing great circles) meet. Rotate the S line of the tracing paper clockwise to the position S. 25° W. of the net and draw a short radial arrow *U* on the paper above the S point of the net. This arrow points S. 25° E., the direction of dip of the upper beds. Roll the S point of the tracing paper anticlockwise

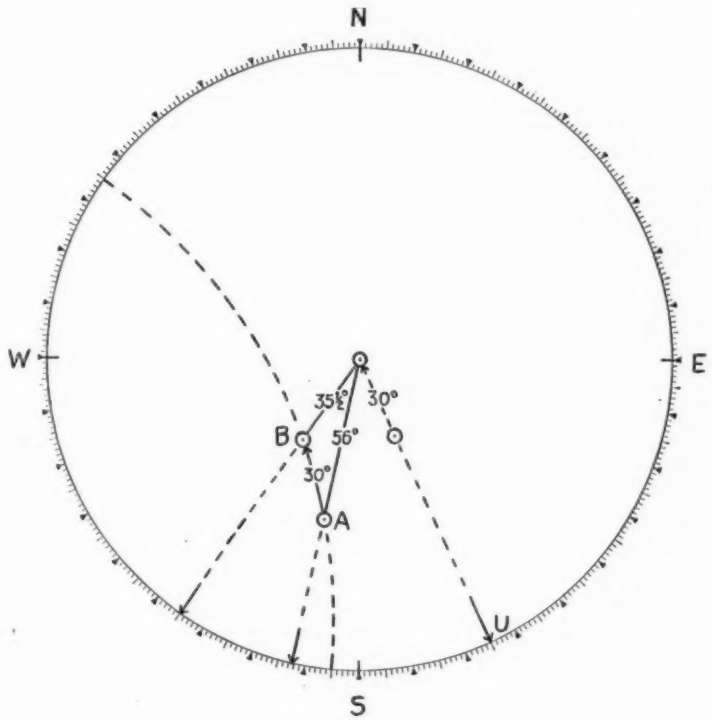

FIG. 3.—Problem of two tilts solved by bedding normals.

to the position S. 12½° E. of the net and along the great circle of the net extending straight south from the center locate a point *A* 56° down from center. This is the pole of the lower set of beds, and represents the normal to a plane dipping 56° to S. 12½° W. Now rotate the tracing paper anticlockwise till the arrow *U* points due east (lies above the equator of the net) and from the pole *A* sketch a line parallel with the nearest small outwardly concave circular arc (representing a small circle) to the left a distance of 30° (the dip of the upper

beds) and locate a second pole *B*. Had a pole representing the upper beds been plotted, a similar rotation would have brought it to the center of the net, that is, where it would have represented horizontal beds. Rotate the tracing paper clockwise till the second pole lies above the south line of the net and note that it is $35\frac{1}{2}°$ from the center and that the S line of the tracing paper lies above S. 35° E., which furnishes the true solution of the problem.

The same problem worked on the Fedorow[10] net, which combines two meridional nets and one polar stereographic net, can be described more simply, but the method is more difficult to understand and because of the large number of lines on this type of net errors can more easily appear; also since the graduations are generally 5° apart (rather than 1° or 2° as on the simpler net) the result is likely to be less accurate. Plot a point 56° to S. $12\frac{1}{2}°$ W., rotate this clockwise 25° parallel with the nearest (55°) small circle whose center lies at the center of the net. Now slide it north 30° along a line parallel with the nearest small outwardly concave circular arc (the one 30° west from the center of the net) and finally rotate it back (anticlockwise) 25° parallel with the nearest (35°) small circle whose center lies at the center of the net, locating a pole approximately 35° to S. 35° W., the answer.

The Kohlschütter[11] net with slight modifications is an ideal net for solving problems involving spherical triangles such as the one cited. This net consists of a 20-cm. diameter meridional stereographic net printed in black on cardboard overlain by a similar net printed in red on a sheet of colorless, transparent cellulose acetate. The two are joined by a staple through their centers, so that the upper net may be rotated with respect to the lower one. If blue circles and green radiating lines (compare Figure 2) are added to the cardboard net[12] (temporarily removing the plastic sheet to accomplish this), one has in effect a Federow net at 2° intervals with a movable set of "Wulff circles." With what are designated the N and S points of this movable net at the ends of what is really its equator, the solution of the problem given requires just one setting, namely, place the S point of the movable net over S. 25° E. on the fixed net. Now find the pole located 56° to S. $12\frac{1}{2}°$ W. on the fixed net; from here go 30° northwesterly parallel with the nearest outwardly concave circular arc of the mov-

[10] A. Johannsen, *Manual of Petrographic Methods* (1918), p. 15. A. N. Winchell, *Elements of Optical Mineralogy*, Part I (1937), Pl. III.

[11] E. Kohlschütter, *Messkarte zur Auflösung sphärischer Dreiecke* (1936). Price, 8 marks, from Dietrich Reimer Verlag, Berlin SW 68.

[12] An alternative is to add an arm pivoted at the center of the net made of a rectangular piece of transparent cellulose acetate. On this mark a radial line crossed by short arcs corresponding to the circles of Figure 2.

able net, and read (on the fixed net) 36° to S. 35° W., the approximate answer.

APPENDIX

Practically any problem of structural geology involving planes and lines at one point of observation and capable of mathematical solution can be handled with the stereographic projection. In many cases, excepting only the simplest types of problems, this mode of attack is both time-saving and elucidating, and the results may be obtained with an entirely satisfactory degree of accuracy. Those whose earlier training has included descriptive geometry tend to prefer this line of attack, because they think it enables them better to visualize the problem. The writer's teaching experience convinces him that this is not so.

The projection has been known and used by astronomers, cartographers, and navigators since Ptolemy (probably derived from Hipparchus). It was of value in the manufacture of astrolabes, and as early as 1624 a meridional stereographic net of 11½ inches in diameter graduated to single degrees was described by Metius for the graphical solution of spherical triangles.[13] It received its present name in 1613 by Aguilonius, and some people speak of such a projection as a stereograph, although this term is more commonly applied to a stereoscopic pair of drawings or pictures. F. E. Neumann introduced the projection to crystallography in 1823 and it or the gnomonic is described in nearly every modern serious book covering this field. S. L. Penfield was the first American crystallographer to describe it in detail, and his exposition of its uses in connection with maps[14] would be of interest to most geologists today. Apparently it has not been used by the structural geologists of this country except for Bucher's work[15] on joints, though O. Seitz[16] and others have found it of value.

The following remarks of an explanatory nature may appeal to those who have never worked with a stereographic net. Imagine the eye located at 0° lat. and 0° long. on the surface of a transparent terrestrial globe (in the Gulf of Guinea nearly 400 miles south of the Gold Coast) and that you are looking at the hemisphere opposite the eye, extending from 90° W. long. across the Pacific to 90° E. long.

[13] A. Hutchinson, "On a Protractor for Use in Constructing Stereographic and Gnomonic Projections of the Sphere," *Mineralogical Magazine*, Vol. 15 (1908), p. 106.

[14] *Amer. Jour. Sci.*, Vol. 11 (1901), pp. 121–37.

[15] W. H. Bucher, "The Mechanical Interpretation of Joints," *Jour. Geol.*, Vol. 28 (1920), pp. 716–18.

[16] Conveniently summarized in R. Sokol, *Geologisches Praktikum* (1927), pp. 151–53, 173–75, 198–99, 207–08, 211.

Now if you neglect all features of the globe except the longitude (great) and latitude (small) circles spaced at 2° intervals, you are seeing the standard net as shown in Figure 1.

When a stereographic projection is made on tracing paper above the net, the plane of projection is generally *not* a meridional one of the sphere of reference, as is the net itself, but is its equator; the eye is at one pole and sees the opposite hemisphere. At first thought one might consider that a polar (equatorial) net (as shown in Figure 2) would be in order, but this is not so, as everything that can be done with a polar net, and *much more*, can be done with a meridional net, provided either the net or the tracing paper can be rotated about an axis perpendicular to the center of the net.

When working structural problems with a meridional stereographic net, it is simplest to consider the eye as being in the direction of the zenith, directly above the point where the field observations are made. The latter point lies at the center of the sphere of projection, the eye at its upper pole.[17] The plane of projection which is the equatorial plane of the sphere of reference is thus tangent to the surface of the lithosphere at the point of observation. The planes which represent the bedding surface at this point, or the joint or cleavage or fault surfaces in various types of problems, may be thought of as planes of definite orientation through the center of the sphere, thus cutting the latter in great circles.[18] Consider only the projection of the lower half of the sphere upward onto its equatorial plane, and then the problem given earlier (third paragraph) is solved as shown in Figure 4, which is supposed to represent a piece of tracing paper that lay above a meridional stereographic net. The circular arcs were obtained as follows.

Having prepared the net and paper as described in the early part of the fourth paragraph, first rotate the tracing paper about its center (which coincides with the center of the net), so that its N point lies above N. 65° W. of the net (65° is the complement of 25°, and the upper beds dip 30° to S. 25° E.) and draw the arc UU' shown as a continuous line by tracing the great circle from the net that lies 30° in along the equator from the E point of the net. The diameter of the net connecting the ends of this arc may also be drawn. Now if the tracing paper is rotated back to its initial position, the appearance is as shown in Figure 4. The arc UU' represents the half great circle

[17] Bucher (*op. cit.*) drew the projection as if the eye were looking towards the zenith rather than away from it.

[18] When planes are so indicated, the projection is known as the cyclographic, the latter bearing the same relation to the ordinary stereographic as does the linear (Federow) to the gnomonic.

that a bedding plane dipping 30° to S. 25° E. would make on the lower half of a sphere of reference if viewed from its upper pole (and thus projected diagonally upward to its equatorial plane). The diameter represents the intersection of this bedding plane with the equatorial plane of the sphere of reference, and so depicts the strike of the upper beds of our problem.

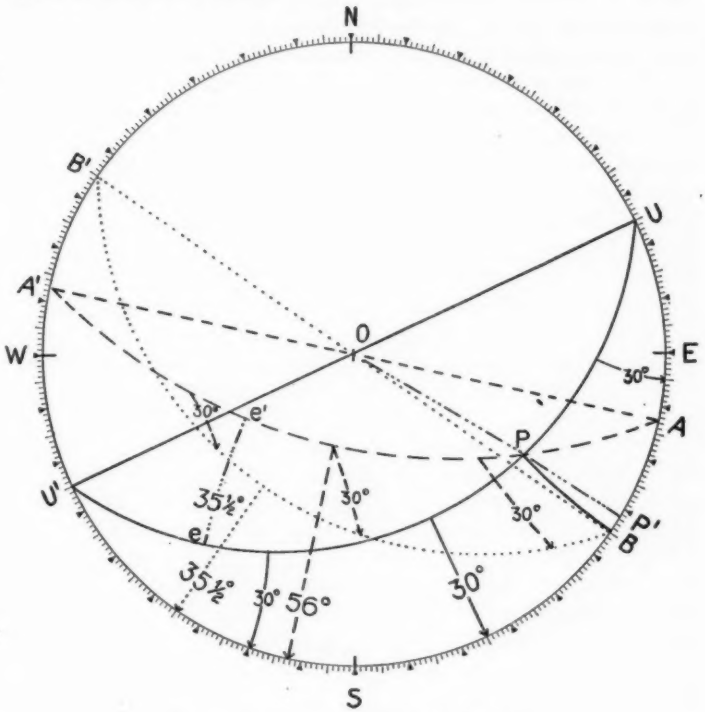

FIG. 4.—Problem of two tilts solved by planes.

Now rotate the tracing paper so that its N point lies above N. 77½° E. of the net and trace from the net the great circle in 56° along its equator from its west point. Also trace the corresponding diameter and rotate the net back to its initial position. The result is as shown by the dashed arc AA' and diameter (Fig. 4), which represent the lower beds of dip 56° to S. 12½° W. after the second tilt.

The problem is to tilt both sets of beds until the upper ones become horizontal. Rotate the tracing paper until its N point lies above N.

65° W. of the net, that is, into the position used for drawing the continuous-line arc representing the upper beds. If this arc considered as being on its hemispherical surface is rotated about the N–S axis of the net 30° upward it will be brought into the plane of reference, the horizontal position. This is attained by sliding each point of the arc through 30° to the right along the small circle of the net above which the point in question lies. This brings the arc into coincidence with the right side of the net. This rotation is shown in Figure 4 by continuous-line 30°-arrows for three points and also by arc *PB*.

Now with no change in position of the tracing paper similarly slide two or three convenient points of the dashed-line arc 30° to the right along their small circles as is shown by the three dashed 30°-arrows as well as the arc *PB*. Rotate the tracing paper till the points represented by the tips of these three arrows lie above some one great circle of the net, and trace off this arc *BB'* and its diameter (dotted lines in Figure 4). In this position the N point of the tracing paper is above N. 55° E. (or S. 55° W.) of the net. Add the dotted line extending from the middle of the dotted arc outward along the equator of the net to the W point of the net and note that this is $35\frac{1}{2}°$ in length. Rotate the tracing paper to its initial position as shown in Figure 4 and the bearing of the dotted $35\frac{1}{2}°$-line is seen to be S. 35° W., the required answer.

In working the problem it is unnecessary to draw all the arcs shown in Figure 4. Simply rotate the tracing paper so that its N point is above N. $77\frac{1}{2}$ E. of the net (lower beds) and locate three points of the dashed arc, its two ends and the middle point above the equator of the net. Now rotate the tracing paper so its N point is above N. 65° W. of the net (upper beds) and slide the mid-point and the SW end-point 30° along small circles of the net, locating two new points. These latter determine the arc represented by dotted lines in Figure 4. This gives the answer as described in the preceding paragraph.

An alternative method of solving the problem using the construction of Figure 4 may be of interest. From *P*, the point of intersection of the continuous and dashed arcs,[19] and having the continuous arc above a great circle of the net (e.g., with N of the tracing paper above N. 65° W. of the net), measure the arc *PU*, which is 60°. This is the same as the angle *UB*,[20] hence serves to determine the direction of

[19] Straight dot-and-dash line *OP* is the direction of contact of the planes of the lower and upper beds. Extended to the circumference at *P'* this line is seen to have a bearing S. $58\frac{1}{2}°$ E., its horizontal trend. It dips $25\frac{1}{2}°$ (=*PP'*) in this direction.

[20] Since triangle *PUB* is isosceles as by construction *UPB* and *UBP* are both right angles and *UP* and *UB* are great circle arcs.

strike of the lower beds before the second tilt. Now locate e, 90° from P along the continuous arc; rotate the tracing paper till the dashed arc is above a great circle of the net and locate e', 90° from P. Rotate the tracing paper till e and e' lie above a great circle and join them by a dot-and-dash arc which is seen to be $35\frac{1}{2}°$ in length;[21] this is the angle between the upper and lower bedding planes, which is the amount of dip of the lower bedding plane before the second tilt.

In solving problems involving directions within planes such as slickensides on faults, outcrop lines of beds, joints, or faults on smooth surfaces (canyon or quarry walls, flat exposures), elongation of minerals in cleavage surfaces, flow lines in flow layers, it is in general simpler to handle the problem in terms of planes (as is done in this appendix) rather than as directions normal to planes. However, since the distance representing 1° at the center of the net is only half as far as the same angular distance at the edge of the net, working near the edge of the net yields more accurate results. Therefore when dips are small, use the method of planes; when large, use the plane-normal method.

[21] The arc ee' may be determined by rotating the tracing paper till P lies above the equator of the net; then from P count 90° going along a straight line through O and trace off the great circle of the net lying under the point thus located.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 9 (SEPTEMBER, 1938), PP. 1272-1279, 3 FIGS.

GEOLOGICAL NOTES

EFFECT OF ANGULARITY OF GRAIN ON POROSITY AND PERMEABILITY OF UNCONSOLIDATED SANDS[1]

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The factors affecting the porosity and permeability of aggregates of solid grains have been exhaustively discussed by Fraser.[3] With respect to the effect of shape of grain, he says[4] that aggregates of the highest porosities are obtained only with the very angular platy and needle-like particles and that, in general, increase in angularity of grain increases porosity. The only exception he finds is in the case of grains that are "mildly and uniformly disc-shaped." With respect to permeability as a function of angularity, he holds[5] that the permeability of an aggregate will increase as the form of the grains departs from that of a true sphere.

In the course of some studies of unconsolidated sands, permeabilities of the single component separates from screen-sizing were determined in apparatus, and according to procedure, which conformed to the A.P.I. specifications.[6] Previous to this, report[7] had been made of a study of the effect of grain shape on porosity. In both studies, materials were used the grains of which were somewhat equidimensional (not platy or acicular), and for which it was thought that the projected outlines permitted a measure of the sphericity.

In Figure 1, the points on the curves are numbered to correspond with the sample numbers. The horizontal axis is scaled in terms of the "roundness-number,"[8] which is defined as the area of a grain divided by the area of its smallest circumscribing circle. The other

[1] Manuscript received, June 16, 1938.

[2] Stanford University.

[3] H. J. Fraser, "Experimental Study of the Porosity and Permeability of Clastic Sediments," *Jour. Geol.*, Vol. 43 (November-December, 1935), pp. 910–1010.

[4] *Ibid.*, p. 938.

[5] *Ibid.*, p. 962.

[6] American Petroleum Institute, "Standard Procedure for Determining Permeability of Porous Media," *A.P.I. Code No. 27* (1935).

[7] F. G. Tickell, O. E. Mechem, and R. C. McCurdy, "Some Studies on the Porosities and Permeabilities of Rocks," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 103 (1933), p. 254.

[8] *Cf.* F. G. Tickell, *The Examination of Fragmental Rocks* (1931), p. 6.

variable is porosity in the case of one curve, and a so-called "dimensionless permeability factor" in the case of the other curve. The latter named is a ratio obtained by dividing the permeability by the square of the average grain diameter. This dimensionless quantity is useful in comparing with other dimensionless properties, such as porosity, roundness, and the like. Parenthetically, it may be said that flow experiments through unconsolidated sands have shown[9] that one-

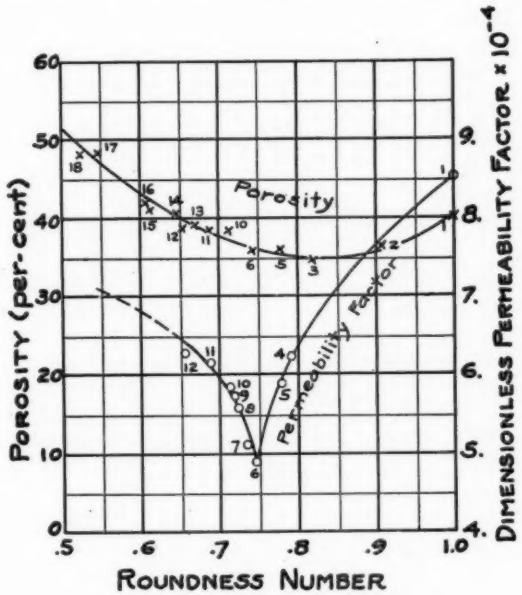

FIG. 1

half the reciprocal of this quantity is equal to the friction factor for a Reynolds-number of one, providing that all quantities are in the c.g.s. system of units (1 c.g.s. permeability unit = 1.0131×10^8 darcy).

The interesting point of the figure, here given, is that a minimum porosity is shown for a roundness-number of 0.82, and a sharper minimum permeability is shown for approximately the same roundness-number (0.75). It would seem that sub-angular grains of about this roundness-number, while in the state of chance packing, interdigitate in such a way as to reduce the interstices to a minimum.

[9] W. N. Hiatt, *A Study of the Permeabilities of Unconsolidated Sands*, engineer's thesis, Stanford University (1938).

In these experiments the grains were aggregated, by vibration, into a chance packing, as defined by Graton and Fraser.[10] The porosity and permeability of tightest chance packing are unique for a given sand, whether it is a single- or multi-component mixture. That such packings recurred was demonstrated by the duplicability of results.

The data for the points defining the curves are given in Table I.

TABLE I

Sample No.	*Tyler Mesh*	*Dimensionless Permeability Factor* ($x_{.10^{-4}}$)	*Roundness-Number*	*Porosity Per Cent*	*Material*
1	3.05 mm.	8.54	1.000	40.4	Lead shot
2	5.61 mm.	—	.905	36.8	Manchurian peas
3	8/10	—	.817	34.7	Mustard seed
4	24/28	6.28	.792	36.2	Ottowa silica sand
5	28/32	5.93	.779	36.4	Ottowa silica sand
6	32/35	4.91	.749	36.2	Ottowa silica sand
7	35/42	5.14	.735	37.4	Ottowa silica sand
8	42/48	5.60	.722	37.8	Ottowa silica sand
9	48/60	5.76	.718	38.2	Ottowa silica sand
10	60/65	5.88	.711	38.5	Ottowa silica sand
11	80/100	6.19	.688	38.9	Ottowa silica sand
12	100/115	6.28	.653	39.05	Ottowa silica sand
13	24/28	—	.668	39.4	Beach sand
14	24/28	—	.647	40.6	Amber silica sand
15	32/35	—	.614	41.2	Amber silica sand
16	80/100	—	.608	42.1	Belgian silver sand
17	10/12	—	.548	48.6	Crushed ferro-molybdenum
18	10/14	—	.525	48.1	Crushed quartz

[10] L. C. Graton and H. J. Fraser, "Systematic Packing of Spheres—with Particular Relation to Porosity and Permeability," *Jour. Geol.*, Vol. 43 (1935), p. 879.

WILCOX EOCENE PRODUCTION AT SEGNO FIELD, POLK COUNTY, AND CLEVELAND FIELD, LIBERTY COUNTY, TEXAS[1]

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Houston, Texas

On May 26, 1938, the Gulf Oil Corporation completed its Adolphus Ragan No. 2, I. and G. N. R.R. Survey, abstract 713, Segno field, Polk County, Texas, through 12 shots in the casing from 8,161-65

[1] Published with permission of the Gulf Oil Corporation. Manuscript received, July 11, 1938.

[2] Gulf Oil Corporation.

feet. The initial production on a 24-hour test, ¼-inch positive choke, was 632.73 barrels. The well was spudded, December 21, 1937, and drilled to a total depth of 9,154 feet, and then plugged back to the producing depth.

The well is of particular interest since its production is the first in the Segno field from the Wilcox group of the Eocene. Previous production has been from the Cockfield-Yegua section of the Eocene.

On June 21, 1938, the Gulf Oil Corporation completed its Kirby Lumber Company "C" No. 21, John Pleasant Survey, abstract 327, Cleveland field, Liberty County, Texas, through 23 shots through the casing from 9,089-99 feet. The well made a gas distillate well. It was spudded, January 20, 1938, and drilled to a total depth of 10,075 feet, and then plugged back to the producing depth.

Kirby Lumber Company "C" No. 21 is producing from the Wilcox group of the Eocene. As with previous production from the Segno field, previous production from the Cleveland field has been from the Cockfield-Yegua section of the Eocene.

The section drilled between the top of the *Ceratobulimina eximia* zone (approximately the top of the Cook Mountain) and the top of the Wilcox in both Segno and Cleveland is somewhat different from the same section penetrated by wells updip from these two fields. The chief differences are found in the greater thickness of the section and in the general absence of sands.

Conflicting views were current regarding the age of the production from these two wells previous to the detailed examination of the samples. Two theories were advanced. One was that the producing sand, rather than being of Wilcox age, was Sparta with a greatly thickened Cook Mountain section. The other was that the sand was Queen City with a thickened Cook Mountain-Weches section. Samples have been examined from both the Ragan No. 2 and the Kirby Lumber Company "C" No. 21, as well as other deep wells in the general area. Strike and dip cross sections have been made. From all the evidence obtained the Wilcox age of the producing horizon seems well established.

Ragan No. 2 was drilled some distance into the Wilcox and penetrated beds containing *Discocyclina cookei* at 8,722–27 feet, or approximately 600 feet below the top of the Wilcox. As far as known, *Discocyclina cookei*[3] is restricted to the Salt Mountain member of the Wilcox.

[3] *See* Donald W. Gravell and Marcus A. Hanna, "Subsurface Tertiary Zones of Correlation through Mississippi, Alabama, and Florida," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 8 (August, 1938), pp. 984–1013.

Figure 1 gives the correlation between the Ragan No. 2 and the Kirby Lumber Company "C" 21. The section between the top of the

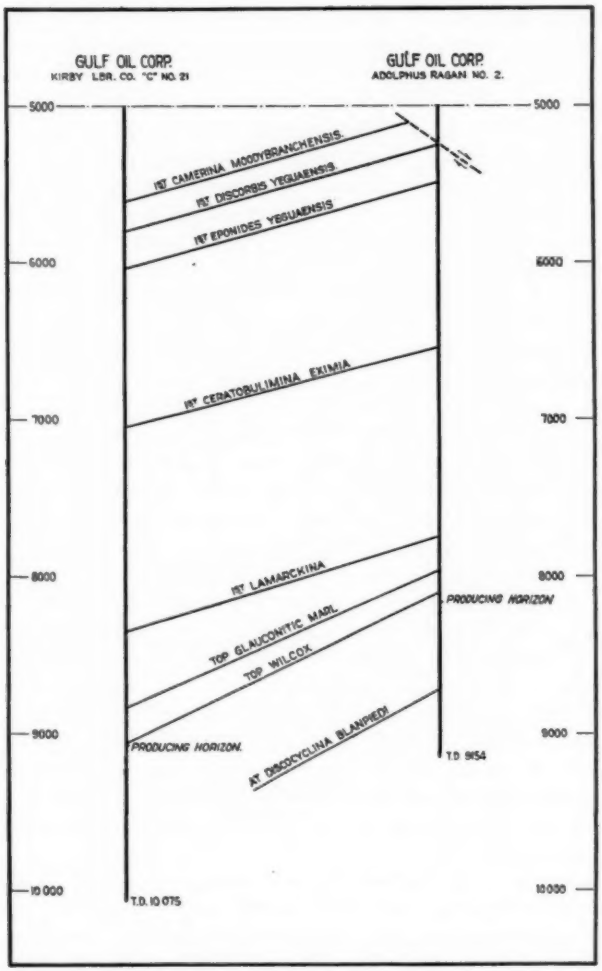

FIG. 1

Ceratobulimina eximia zone and the top of the Wilcox was almost devoid of sandy material. The sands of the Sparta, which lies above the *Lamarckina* zone, are absent. The sands of the Queen City, which

lies below the Weches (represented by *Lamarckina*), are represented by silty shales. The glauconitic marl below these silty shales is assumed to be the equivalent of the Reklaw.

Although many reliable lithological and faunal changes were found in the samples between the top of the *Ceratobulimina eximia* and the top of the Wilcox in both wells, no indication of these changes was found in the Schlumberger electrical logs, since the changes were in the character of shales and not alternations of sands and shales.

SHREVEPORT FIELD, CADDO PARISH, LOUISIANA[1]

M. W. GRIMM[2]
Shreveport, Louisiana

On July 15, 1938, R. E. Allison completed Ellerbe No. 1 in the center of the SW. ¼ of the NW. ¼ of Sec. 27, T. 18 N., R. 14 W., Caddo Parish, Louisiana, from the Pettit zone in the basal part of the lower Glen Rose formation of the Trinity group, after plugging back from a total depth of 6,025 feet. Surface casing was set at 2,048 feet and the final string, 7-inch O. D., was set at 5,943 feet.

The well was gun-perforated with 59 shots from 5,549 to 5,570 feet and actually produced 499 barrels of 43.8° gravity crude in 24 hours through a ¼-inch tubing choke. Tubing pressure was 1,325 pounds; casing pressure was 1,525 pounds; bottom-hole pressure was 2,602 pounds; fluid level was 1,800 feet below the surface; and the oil-gas ratio was less than 1 to 500. The well tested salt water between 5,826 and 5,827 feet in the contact zone between the lower Glen Rose formation and the Travis Peak formation.

The surface elevation of the well is 173 feet, derrick floor. The "Massive anhydrite" was encountered from 4,335 to 4,595 feet; the "lower stringer" of anhydrite from 4,662 to 4,695 feet; the Jeter zone from 4,782 to 4,858 feet; the Pettit zone from 5,547 to 5,620 feet; the top of the Glen Rose red beds at 5,724 feet; a sand at the contact of the Glen Rose and the Travis Peak from 5,824 to 5,858 feet; and the top of the Travis Peak formation at 5,880 feet.

The location of the well is about one mile north of the city limits of Shreveport and in the Cross Lake area of the Shreveport field, which formerly produced commercial gas from the Nacatoch formation at approximately 950 feet, and from the contact of the Upper and Lower Cretaceous formations at approximately 2,500 feet. The

[1] Manuscript received, August 6, 1938.

[2] Petroleum geologist.

Pettit now produces oil at Shreveport, Sligo, and Lisbon and gas-distillate at Sligo, Rodessa, and in Panola County, Texas, showing a wide distribution of this zone.

The Shreveport field has a closure of about 125 feet on top of the Nacatoch; a seismograph survey on the "Massive anhydrite" shows a closure of 250 feet. The structure is one of low relief and for that reason should be more productive of crude oil rather than gas-distillate, as has been the case of the fields or structures of greater closure and higher relief in the Arkansas-Louisiana-Texas region. In addition to the Pettit zone, the field has possibilities of production from the Jeter zone at approximately 4,800 feet, from the Travis Peak formation between 6,100 and 6,500 feet, and from the "lower Marine" beds at about 8,500 feet.

MICROSCOPE ECLIPSE PLATE FOR ROUTINE INDEX DETERMINATIONS[1]

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The use of the optical method[3] for the identification of nonopaque minerals that requires only a microscope and a set of immersion oils is becoming more popular as the many advantages of this method are better known. This method is simple and inexpensive both in time and material once the apparatus is at hand and the requisite manipulatory experience has been acquired. When only minute fragments of a mineral are available it is often the only satisfactory means for identification.

In the routine examination of drill samples and cores from test wells, the range of minerals from any geologic province is commonly limited in number and most of these minerals can be recognized by sight or by the use of the binocular microscope. The few remaining unknown minerals require identification by some positive means, and the optical method may often serve to accomplish this result in less than a few minutes time.

The operation of determining the indices of refraction may be accomplished in a number of ways: (1) use of the finger below the microscope stage to intercept the light; (2) by shifting the substage mirror; or (3) by inserting a card or plate in the body-tube of the microscope.

[1] Manuscript received, August 19, 1938.

[2] United States Geological Survey.

[3] E. S. Larsen, "The Microscopic Determination of the Nonopaque Minerals," *U. S. Geol. Survey Bull. 679* (1921), 2nd Edit., *Bull. 848* (1934).

The writer prefers the third method and has devised a simple eclipse plate[4] that may be inserted in the body-tube of the microscope and left in position without interfering with any other operation of the microscope that does not require use of the slit. The eclipse slide is

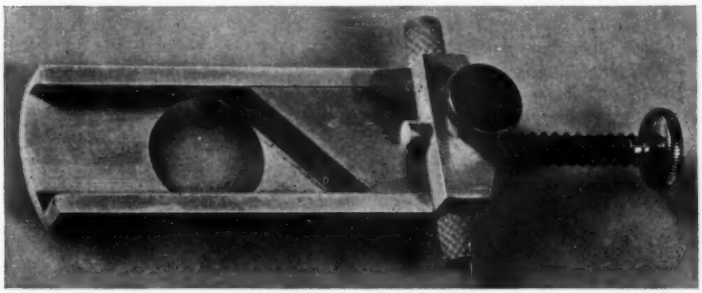

FIG. 1.—Eclipse plate for petrographic microscope. Illustration 1½ size.

held in an open position by a spring or may be held at any degree of eclipse by a set-screw. To operate the slide requires only slight finger pressure on the plunger. The major advantages that this plate has over other make-shift methods are the ease of operation and the assurance of uniformity of the eclipse effect.

[4] Made by the Spencer Lens Company, Buffalo, New York.

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DISCUSSION

NAMING SUBSURFACE FORMATIONS[1]

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Language, being a means of communication, is a collective product. It is invented not by isolated individuals but by people in groups to express to each other common impressions of external nature, and their relations to it and to each other. It is the mass of the people through whom language has had a continuous, evolving history. Literature and science have flowered from this substratum and must continue to draw their life from this soil.

For a few hundred years modern sicence has had also a separate life of its own. It has also evolved within itself, while interacting with the daily run of affairs. It follows that scientists have composed scientific languages, giving precise definitions to common words and inventing new terms. Scientific language is more consciously, precisely, and deliberately constructed, and by a smaller group, than any other kind of language.

But scientific language is still a collective product. Though a term may be invented by an individual scientist, or sponsored by a small authoritative group, it has no validity unless it gains currency with the general run of workers in the particular field to which it applies. Even scientific nomenclature must meet the democratic test of daily use. It can not be "enforced"[3] from above.

These remarks are prefatory to the expression of a personal opinion on the question of nomenclature of sedimentary formations. It is probable that the majority of members of the Association have been as remiss as the writer in reading and remembering the proposed rules of "Classification and Nomenclature of Rock Units."[4] The writer believes that the Association's committee on geologic names and correlations should devote itself to publicizing these rules to local groups as the best means of "enforcement."

As it applies to the Permian basin of West Texas and New Mexico, the writer takes exception to Article 17,[5] which reads:

> Subsurface units shall be given formal names only where names are necessary for adequate presentation of the geologic history of the region.
>
> *Remarks.*—(*a*) Subsurface units, recognized and named from well logs with the assistance of data derived from cuttings or cores, have a special status by virtue of the fact that the type data are usually indirect and the type locality, at best, is accessible only during the original work. Even when all materials are preserved by the original author and can be inspected by later students, it will never be possible to repeat the original work in the same manner as when dealing with exposed formations. It is desirable,

[1] Manuscript received, July 5, 1938.

[2] Argo Oil Corporation.

[3] John G. Bartram, "Use of Stratigraphic Names," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 6 (June, 1938), p. 763, 2d par.

[4] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 7 (July, 1933), pp. 843–63.

[5] *Ibid.*, p. 857.

therefore, to keep the number of formal names applied only to subsurface units as small as possible.

. . . .

(*c*) When it becomes possible to correlate a named subsurface unit with a named surface unit, the name of the surface unit is to be applied, even though the subsurface name has priority.

This rule seems to reflect the attitude of surface geologists to subsurface data in areas where the technique of taking adequate samples of well cuttings is not as well developed as in the Permian basin. Here samples are seldom finally examined on the derrick floor; they are studied in the subsurface laboratories and are as available at a later date as when the well was drilled. Article 17 seems to imply that only by being present during the actual drilling of the rock can a geologist gain an accurate knowledge of subsurface formations, but even the surface geologist is unable to observe how his exposed formations would respond to the bit. That hardly seems to be indispensable information.

More likely the real meaning of Article 17 is to place doubt on the accuracy of sample gathering by tool-dressers and scouts and to emphasize the impossiblity of verifying the measurement of thickness of beds except at the unique time when each sample is taken. This objection is more apparent than real. Sample gatherers in the Permian basin have had good training during a period of a dozen years, and special care is taken on many wildcats and many company wells in the producing fields. Ordinary well measurements are of a higher order of accuracy than all but the most careful measurements of surface geologists. Unlike geologic field work, measurements in wells are virtually unaffected by dips up to 15° (though crooked holes are a source of error). Repeated measurement is necessary to accuracy in all scientific work. This requirement is fulfilled again and again in subsurface study of the Permian basin by the drilling of near-by wells. We already know we are right as to thickness; but we shall also have innumerable verifications in the future.

The demand for complete uniqueness of measured section is not justifiable; some details of almost all type sections must be filled in from near-by exposures. We have in the Permian basin great numbers of complete, detailed, measured sections studied by tens of geologists, and still available for critical restudy. These are pristine sections, not largely covered by talus slopes, not discolored by weathering or distorted by slumping. What the subsurface geologist here loses in not being able to follow the third dimension around the hill, he gains in having so wide a distribution of completely exposed, measured, sampled sections to describe.

The hundreds of Permain basin geologists who use the formation names daily throughout the year are subsurface geologists. The nomenclature must be designed for their needs. Nearly 10 years ago the name "Yates sand" was applied to an important, widespread member, and it has been in general use ever since. If some surface geologist, spending a week in the field, should find the Yates outcrop near Hootinannie post office and propose to call it the "Hootinannie sandstone," it is too much to ask all the workers of the Permian basin to change from Yates to Hootinannie because Article 17 says they should.

In this province subsurface information deserves equal rank with surface information.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 9 (SEPTEMBER, 1938), PP. 1282-1291

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

THE FLOW OF HOMOGENEOUS FLUIDS THROUGH POROUS MEDIA, BY M. MUSKAT

REVIEW BY CHARLES R. FETTKE[1]
Pittsburgh, Pennsylvania

The Flow of Homogeneous Fluids through Porous Media. By M. Muskat, with an introductory chapter by R. D. Wyckoff. 763 pp., 284 figs. 6×9 inches. McGraw-Hill Book Company, New York (1937). Price, $8.00.

Dr. Muskat's comprehensive treatise on *The Flow of Homogeneous Fluids through Porous Media* covers a field of fundamental importance to petroleum engineers and geologists, in which, heretofore, no adequate text or reference book has been available. It is the outgrowth of 6 years of investigation on the part of the author in collaboration with R. D. Wyckoff and other members of the staff of the Gulf Research and Development Company.

A homogeneous fluid is defined as consisting essentially of a single-fluid phase which may be either a gas or a liquid, but mixtures of the two resulting in gas-liquid interfaces are excluded. The term "homogeneity" as used applies only to mixtures of fluids which are completely miscible and remain so throughout the system. Although it is realized that most of the fluid systems encountered in oil production are heterogeneous in nature and hence are excluded by the foregoing definition, the author believes that most of the discussion which has a bearing on flow systems of the type involved in oil production can, with careful and discriminating interpretation, be applied with at least qualitative validity to oil-production problems.

A porous medium is one possessing a complete multiple interconnection of minute openings. Its distinctive feature is that in a linear flow system involving such a medium the velocity, when considered macroscopically across the whole channel, is uniform. In contrast, in a pipe or single capillary tube the velocity is not uniform but with viscous flow has a parabolic distribution across the section with the maximum velocity at the center of the channel.

In discussing the problems arising in the production of oil or gas, the author confines himself mainly to the flow features of the oil or gas reservoir rather than in the production-engineering phases. Applications of the theory to practice are not confined solely to petroleum engineering; the entire field of ground-water hydrology is covered.

The treatise is divided into four parts: foundations, steady-state flow of liquids, the nonsteady-state flow of liquids, and the flow of gases through porous media.

Under Foundations, R. D. Wyckoff in the introductory chapter describes in concise manner the geological features involved in the flow systems under consideration. Muskat then discusses the application of Darcy's law to fluid

[1] Professor of geology, Carnegie Institute of Technology. Manuscript received, June 15, 1938.

flow through porous media, namely, that the velocity of flow of a homogeneous fluid through a porous medium is proportional to the pressure gradient, provided the flow is of the viscous and not the turbulent type. It is concluded that when the macroscopic features of the flow as averaged over a large number of pores are considered, the great majority of flow systems in porous media that are of practical interest are governed by Darcy's law.

The permeability of a porous medium, which represents the fundamental constant in Darcy's law, is defined and laboratory methods of measuring it in both unconsolidated sands and consolidated porous media are described in detail. Methods of determining the permeability in the field are also given. Methods of measuring the porosity of porous media, both "total" and "effective" are also described.

Applying Darcy's law to a three-dimensional system, three partial differential equations, one for incompressible liquids, one for compressible liquids, and one for gases, are then developed. These form the starting points for the analyses of the other three parts.

Part II deals with the steady-state flow of liquids. Systems included are those whose dimensions are small or moderate and in which the fluids under consideration are normal liquids whose compressibility is very small. In such systems with change in pressure at the boundaries the time of readjustment of the internal pressure is small and a continuous succession of steady-state distributions follows the variations in boundary conditions without lag.

Two-dimensional flow problems and potential-theory methods are considered first. Since many oil-bearing sands are found to possess considerable uniformity in thickness over large areal extents, they afford problems of this character where the wells completely penetrate the sands, inasmuch as under these conditions vertical variations in the potential distribution may be neglected. Partially penetrating wells are discussed under three-dimensional problems. Fractured limestone reservoirs and the theory of the acid treatment of limestone wells are taken up under systems of non-uniform permeability. Edge-water encroachment and water coning are discussed under two-fluid systems. Well patterns, mutual interference and interaction between wells, off-setting problems, and different types of water-flooding networks are discussed under multiple-well systems.

In Part III, entitled the nonsteady-state flow of liquids, the flow of compressible liquids through porous media is analyzed. Systems involved are those in which, due either to the compressibility of the liquid or the large dimensions of the porous medium, the pressure distributions within the medium lag behind the changes that take place at the boundaries. An interpretation of the pressure decline in the East Texas oil field is used as an illustration of the practical application of the analytical procedure developed. The production is attributed to the "drive" exerted on the oil by the water from the adjacent Woodbine sand which is behaving as a compressible liquid in that it is expanding and occupying the space from which the oil is being removed.

Part IV deals with the flow of gases through porous media. While problems of gas flow are essentially of the nonsteady type, the fundamental decline history of a gas-flow system can be represented by a continuous succession of steady states in which the density declines everywhere uniformly at such a rate as to provide for the instantaneous total flow of the system.

This makes it possible to treat many of the problems encountered in a manner analogous to that of systems involving the steady-state flow of liquids. Among problems discussed are water coning, gas-oil ratios, effect of tubing on the gas-oil ratio, and gas coning in tubed oil wells.

The author presupposes a thorough knowledge of the calculus and some familiarity with the elements of differential equations. To the research engineer and student, Muskat has pointed out in stimulating manner how many of the problems encountered in the particular field of fluid mechanics covered by the treatise can be made to yield to a rigorous mathematical solution. For the average engineer or geologist, who is primarily interested in the results and who may experience some difficulty in following the analytical derivations, extended summaries are provided at the end of each chapter. These give the physical content of the various problems discussed and the salient features brought out by their solution.

ROCK SALT AND POTASH SALTS, BY ERNST FULDA

REVIEW BY R. D. REED[1]
Los Angeles, California

"Steinsalz und Kalisalze" (Rock Salt and Potash Salts). By Ernst Fulda. Part 2 of Vol. III (Coal, Salt, and Petroleum) of *Die Lagerstätten der Nutzbaren Mineralien und Gesteine* (Deposits of Useful Minerals and Rocks), edited by Beyschlag, Krusch and Vogt. 240 pp., 94 figs. Ferdinand Enke, Stuttgart (1938). Price: paper, RM 18.20; cloth, RM 20. Discount of 25 per cent on orders outside Germany.

In two sections, devoted, respectively, to general and regional salt geology Dr. Fulda presents a brief summary of the salt resources of the world along with a much more detailed summary of the German occurrences, a good statement of his own and other geologists' views upon the nature and origin of salt deposits, and some interesting notes upon the history of salt production and of the scientific investigation of salt deposits. Owing to the collaboration of Dr. N. Polutoff, the description of Russian occurrences is fairly detailed and is perhaps the best account to be found in any non-Russian language. The occurrences of other countries, particularly those of non-European countries, are described less adequately.

In the Hallstatt region of the northern Alps salt was mined on a great scale during the prehistoric Hallstatt period, approximately 1,400–500 B.C. Indications of prehistoric salt manufacture are known at Lorraine and in some districts of western Germany. Salt was mined in India in the time of Alexander the Great. Tacitus mentions a war between two German tribes for possession of a salt-bearing stream, perhaps the Werra, which was near the boundary of the lands claimed by these tribes. In the Mediterranean lands, on the other hand, salt was generally obtained in ancient times by evaporating sea water.

In the 18th century von Borlach taught that rock salt occurs underground in regions that have salt springs. This idea led to drilling, and in some parts of Germany to the discovery of salt beds. In 1843 a well near Stassfurt un-

[1] The Texas Company. Manuscript received, June 20, 1938.

expectedly drilled into potash salt, but found rock salt at a greater depth. The latter was produced for several years before, in 1861, potash salts came to be of sufficient value to be mined also. For 3 decades thereafter, the production of potash salt was a monopoly of the Stassfurt region, but by the period of the World War it had spread to several other German districts and has since spread more widely over the world. In North America, the author notes, the discovery and development of salt deposits have largely taken place in connection with the drilling of oil wells.

In 1852 Alberti wrote an important book on salt deposits in which he advocated for them a volcanic origin. His views were disputed in 1855 by G. Bischof, who held that such deposits have been derived from sea water. The views of Bischof were later supported by Ochsenius and others, and are still held. Van't Hoff and his followers have contributed greatly to salt chemistry and Lachmann, Stille, and others to salt tectonics.

Dr. Fulda gives an excellent summary of the data regarding salt minerals and their properties, the rocks with which they occur, of modern views as to the precipitation of the various salts from solution, the behavior of salt under high pressure, the radioactive properties of salt solutions, and the origin of salt deposits. Like many other modern workers he finds the bar theory of Ochsenius attractive but not entirely convincing, and most other theories, including those of Johannes Walther and Dr. Fulda himself, scarcely better. He concludes this part of his discussion with the presentation of a modern theory which seems to answer all our needs, if we can believe it. This is the Great Tidal Flood theory of Martin Wilfarth, presented in the *Geologische Rundschau* during 1933, and mistaken by the present reviewer for simply another outrageous hypothesis. To Dr. Fulda, however, the author of one of the theories for the origin of salt deposits that Wilfarth specifically attacked, it now seems that "the accumulation of great salt masses is better explained by the aid of the Great Tidal Flood theory" than by his own or any other of the earlier theories.

This new theory rests in part on the idea that the Old Earth split up long ago into two parts, one of them the present Earth, the other the Moon. The distance between the two fragments has gradually increased, from nothing worth mentioning to approximately 240,000 miles. At the same time there has been a gradual lessening of the height of ocean tides. In the early days—late Paleozoic, for instance—the tides were recurrently large enough to flood vast areas of low-lying land, adjacent to the shore, to plane off any remaining irregularities left by unfinished stream erosion, to pile up extensive masses of sand like the Buntsandstein and give them those features that have led to endless doubt and disagreement as to their marine or non-marine origin, and to flood subsiding inland basins repeatedly with masses of seawater that remained to evaporate and deposit their content of salts during the dry periods that intervened between tidal floods. Strange as it may seem, this theory is the only one, apparently, that accounts satisfactorily for the great salt deposits of Germany.

In his discussion of the origin of cap rock, Dr. Fulda quotes Goldman's earlier paper (1926) but does not mention the same author's later work or the more recent publications of other American geologists on the same subject.

In the section on Regional Salt Geology the discussion of German deposits, which is well illustrated, occupies 75 pages; that of the deposits of

the rest of Europe, excluding Russia, 30 pages; that of Russian and Siberian deposits, 38 pages; while the last 30 pages of the book are given over to the salt deposits of the rest of the world.

From the preceding account it will be clear that as a discussion of modern German concepts in salt geology and of the salt deposits of Germany and Russia, this volume is of great value. With refererice to the tectonic relations of salt deposits the works of Stille and Lotze, which attack the problems from a somewhat different angle and discuss them in much greater detail, should also be examined. So far as the salt deposits found outside of Germany and Russia are concerned, Dr. Fulda's brief summary will serve for most of us and his references will permit others to find the more extensive accounts they may need. His book should be of considerable use to oil geologists whose work leads them to take an interest in salt domes or other types of salt deposit. The many sketch maps and structure sections to be found in the account of German salt deposits may prôve particularly useful.

THE JACKSON GAS FIELD AND THE STATE DEEP TEST WELL, BY WATSON H. MONROE[1] AND HENRY N. TOLER[2]

ABSTRACT BY THE AUTHORS

Washington, D. C., and Jackson, Mississippi

"The Jackson Gas Field and the State Deep Test Well," by Watson H. Monroe and Henry N. Toler. *Mississippi State Geol. Survey Bull. 36* (University, 1937). 52 pp., 5 figs., 1 pl., 1 structure-contour map. 6×9 inches. Paper.

The Jackson gas field, which was discovered, February 28, 1930, is in and around the city of Jackson, Hinds and Rankin counties, Mississippi. The Jackson structure was first mentioned in 1860 by Eugene W. Hilgard in his "Geology and Agriculture of Mississippi." Two wells were drilled on the edge of the field in 1917 and no additional drilling was carried on until 1928 and 1929.

One hundred ninety-five wells have been drilled on the structure, of which 137 produced gas, 3 produced oil, and 55 were dry. To the end of 1937, a total of 72,340,829,000 cubic feet of gas and 15,000–20,000 barrels of oil have been produced. Ninety gas wells were producing at the end of 1937.

The producing formation is the top of the Selma chalk, which is encountered at a depth of 2,060–2,230 feet below sea-level.

The uplift has been caused by a relatively upward movement during and after the intrusion of an igneous plug. Several wells have encountered igneous rock at approximately 3,000 feet and deeper.

The deepest test drilled in the field was the State of Mississippi's Fee well No. 2, drilled to 5,530 feet. This well penetrated red and gray shale, sandstone, gray quartzite, and several bodies of igneous rock. The formations below 3,200–3,400 feet appear to be Lower Cretaceous (Trinity) in age.

This structure is the result of igneous activity and great vertical move-

[1] U. S. Geological Survey.

[2] Formerly Mississippi State oil and gas supervisor.

ment that affected a large area. Because of its extent and of the fact that the structural and the stratigraphic conditions below the chalk are very complex, it is hazardous to predict what the results of future exploration will be.

OIL AND GAS RESOURCES OF WESTERN KANSAS
BY WALTER A. VER WIEBE

REVIEW BY N. W. BASS[1]
Tulsa, Oklahoma

*"Oil and Gas Resources of Western Kansas." By Walter A. Ver Wiebe. *State Geol. Survey of Kansas Mineral Resources Cir. 10* (1938). 179 pp. Distributed by the State Geological Survey of Kansas at Lawrence, Kansas. Price, $0.30.

Ver Wiebe's report on the oil and gas resources of western Kansas is the most complete compilation on this active region yet published. The report contains not only the history of the development of the oil and gas resources but includes also a description of the geology of the region.

A chapter is devoted to each county in western Kansas that contains oil or gas pools. Each county chapter is illustrated by a sketch map that shows the location and names of the pools, the principal towns, highways, and railroads, and contains a description of the exposed rocks, and the rocks drilled through, a brief summary of the main structural features, and a detailed history of the oil and gas development. Each pool in the county is described briefly. Also a table showing all pools in the county gives the discovery date, number of wells drilled, depth to producing zones, and gravity of the oil in each pool. Important test wells in the county are described, and a summary of the production of the county to the end of 1937 is given.

An interesting illustration in the introductory part of the report is a sketch map of Kansas that shows the westward advance of oil discoveries since prior to 1900. The author relates the history of exploration for oil and gas in Kansas which began near Paola, Miami County, shortly after the drilling of the Drake well in 1859 in Pennsylvania. Oil seeps near Paola attracted the interest of oil men acquainted with the oil seeps near the Drake well. The early development in Kansas was confined largely to the eastern part of the state. By 1914 and 1915 the El Dorado oil field and other pools in Butler and Cowley counties were under development and in 1923 the Fairport pool in Russell County opened the western Kansas exploration which is still under active exploitation. Ver Wiebe points out that more than 60 per cent of all oil produced in Kansas has come from the western part of the state and the importance of the region is steadily increasing. In 1937 western Kansas contained 192 pools which supplied nearly 80 per cent of the total yield of the state.

Tables are included in the report that show the western Kansas total production and the production in 1937, the number of pools, oil wells, gas wells, and dry holes in each county. A graph shows the total production of the state by years. Another graph shows the potentials and allowables by months since October, 1933.

[1] Published by permission of the director, Geological Survey, United States Department of the Interior. Manuscript received, July 4, 1938.

A brief chapter summarizes the gas production and reserves. About 77 billion cubic feet was marketed in 1937. The gas was produced mainly in the Hugoton, Otis, and Medicine Lodge pools. There are 594 gas wells in western Kansas. Descriptions of the gas pools are included with the chapters on the counties in which they are located.

The author points out that of 17 producing stratigraphic units the Arbuckle limestone, or "Siliceous lime," has produced the most oil. The "Mississippi lime," particularly the upper weathered portion of it, known as "chat," has produced much oil and in several fields this zone is the main gas-producing rock. The so-called "Hunton limestone" has produced much oil in Reno, Harvey, and McPherson counties. The Lansing-Kansas City sequence of limestones, which contains the Oswald zones, has produced important amounts of oil in many localities. Only small amounts of oil and gas have been found in the basal conglomerate of the Pennsylvanian series, and other small amounts in the Simpson, or "Wilcox," of the Ordovician system.

The report contains a fund of information and will long be used by geologists, engineers, and oil operators who explore western Kansas.

AN INTRODUCTION TO GEOLOGY
BY A. E. TRUEMAN

REVIEW BY JOHN L. RICH[1]
Cincinnati, Ohio

**An Introduction to Geology.* By A. E. Trueman. 251 pp., 133 figs., 5×7½ inches. Cloth. Thomas Murby and Company (London, 1938). Price, 4 s net.

This is an elementary textbook intended for secondary schools and as such has much to recommend it. It covers briefly all branches of geology except that very scant mention is made of the glacial period and its effects. The treatment is so condensed that one is led to wonder whether the material will be entirely intelligible to a beginning student. With a few exceptions, the material is essentially accurate. The treatment of the "cycle of erosion" is inadequate and confusing and "base level" is used where "grade" would be the proper word.

The illustrations are all pen-and-ink sketches and are mostly simple and easily understood. Simplicity has perhaps been carried too far when the Niagara gorge is shown without the bend at the Whirlpool. The text is tied in closely with the British local geology. Being a very elementary book it is not likely to be of interest to petroleum geologists.

RECENT PUBLICATIONS

ARGENTINA

*"Tertiary Flora from the Rio Pichileufu, Argentina," by Edward W. Berry. *Geol. Soc. America Spec. Paper 12* (July 15, 1938). 149 pp., 11 figs. 56 pls. of which 51 are plates of fossils.

[1] University of Cincinnati. Manuscript received, July 14, 1938.

*"Estudio geológico de la zona al sur del curso medio del Río Deseado" (Geological Study of the Region South of the Middle Course of the Rio Deseado), by Arturo Roll. *Boletin de Informaciones Petroleras* (Buenos Aires), Vol. 15, No. 163 (March, 1938), pp. 17–83; 27 figs., 13 sketches.

AUSTRALIA

"The Structural History of Australia during the Palaeozoic (The Stabilization of a Continent)," by E. C. Andrews. *Jour. Proc. Roy. Soc. New South Wales*, Vol. 71 (1938), pp. 118–87; 1 pl., 7 figs. *Review in *Amer. Jour. Sci.*, 5th Ser., Vol. 36, No. 212 (August, 1938), p. 156.

CALIFORNIA

*"Recent Developments in the North Belridge Oil Field," by Robert N. Williams, Jr. *Summary California Oil Fields* (State Oil and Gas Supervisor, San Francisco), Vol. 21, No. 4 (1936), pp. 5–17; 4 figs. including 2 structure-contour maps and 1 cross section. Published in 1938.

*"Eocene in the Temblor Range; Northwest," by Gerard Henny. *California Oil World* (Los Angeles), Vol. 31, No. 13 (July 5, 1938), pp. 3–7; 3 figs.

*"Calcium-Carbonate Content of Some California Mesozoic and Tertiary Sediments," by Parker D. Trask. *Bull. Geol. Soc. America*, Vol. 49, No. 8 (August 1, 1938), pp. 1169–82; 4 figs.

FLORIDA

*"Marine Pleistocene of Florida," by Horace G. Richards. *Bull. Geol. Soc. America*, Vol. 49, No. 8 (August 1, 1938), pp. 1267–96; 4 pls., 1 fig.

GENERAL

*"Advancements in Acidizing Wells," by W. W. Love. *Petrol. Engineer*, Vol. 9, No. 10 (Midyear, 1938), pp. 25–28; 8 figs.

Minerals Yearbook, 1938, prepared by the U. S. Bureau of Mines. 1339 pp., 70 chaps., 90 illus., complete index. Reviews mineral industry of United States and other countries during 1937. Order from Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $2.25.

**Annotated Bibliography of Economic Geology for 1937*, Vol. 10, No. 2 (July, 1938). 446 pp. Bibliography with annotations of international literature relating to ore deposits, coal, petroleum, and non-metallic products. Prepared under the auspices of the Society of Economic Geologists with funds contributed by the Geological Society of America, the Society of Economic Geologists, the American Association of Petroleum Geologists, Economic Geology Publishing Company, the National Research Council, and others. Economic Geology Publishing Company, Urbana, Illinois. Price, $5.00 per year.

Annual Reviews of Petroleum Technology, Vol. 3 (August, 1938, covering 1937). 490 pp., 9 illus. "A collection of authoritative surveys of recent developments in every aspect of the technology of petroleum." The Institute of Petroleum, Aldine House, Bedford Street, Strand, London, W. C. 2. Price, 10s 6d. Members of the Institute and annual subscribers to the *Journal* may purchase one copy at 5s.

**Table of Open Flow Capacities of Gas Wells*, prepared by the Appalachian Geological Society (1938). 1 sheet 8½×11 inches. Obtained by writing the Appalachian Geological Society, Box 1435, Charleston, West Virginia.

GEOPHYSICS

*"Newer Trends and Methods in Geophysical Petroleum Exploration," by J. Brian Eby. *Petrol. Engineer*, Vol. 9, No. 10 (Midyear, 1938), pp. 31–40; 7 figs.

Practical Seismology and Seismic Prospecting, by L. Don Leet. 430 pp., 185 figs. 6×9 inches. Cloth. D. Appleton-Century Company, 35 W. 32nd Street, New York. Price, $6.00. "The book provides a readily understood introduction to the scientific study of earthquakes and an exposition of methods of investigating rock structures."

*"A New Method of Depth Determination in Earth-resistivity Measurements," I. E. Rosenzweig. *Amer. Inst. Min. Met. Eng. Tech. Pub. 931* (August, 1938). 10 pp., 9 figs.

*"Round Table on Geophysical Education," *Amer. Inst. Min. Met. Eng. Tech. Pub. 950.* 39 pp., 8 figs.,1 table. Contains five papers by Sherwin F. Kelly, M. King Hubbert, C. A. Heiland and Dart Wantland, David A. Keys, and Donald C. Barton, with discussion.

*"A New Gravimeter for Ore Prospecting," by Helmer Hedstrom. *Ibid., Tech. Pub. 953.* 23 pp., 19 figs., 2 tables.

*"Practical Results Obtained from Geophysical Surveys," by Hans Lundberg. *Ibid., Tech. Pub. 954.* 29 pp., 22 figs., 1 table.

*"Gravity at Sea by Pendulum Observations," by Albert J. Hoskinson. *Ibid., Tech. Pub. 955.* 7 pp.

ILLINOIS

"Gumbotil as a Source of Rotary Drilling Mud, Bonding Clay and Bleaching Clay," by J. E. Lamar, R. E. Grim, and R. M. Grogan. *Illinois State Geol. Survey Cir. 39* (Urbana, 1938). "A mimeographed progress report on the study of Illinois surficial clays which suggests the possible suitability of some deposits of gumbotil (a weathered glacial clay) for the above uses. The origin, nature, distribution and overburden of gumbotil in Illinois are also briefly described." Price, gratis, one copy mailed for 3 cents mailing cost.

JAPAN

*"Tertiary Orogeny in Hokkaidô," by Takumi Nagao. *Jour. Faculty of Sci.*, Hokkaidô Imperial University (Sapporo, Japan), Ser. 4, Geology and Mineralogy, Vol. 4, Nos. 1–2 (March, 1938), pp. 23–30; 1 fig.

*"Molluscan Fossils of the Hakobuti Sandstone of Hokkaidô," by Takumi Nagao and Ken-itirô Ôtatume. *Ibid.*, pp. 31–57; 4 pls. of fossils, 1 fig.

*"Some Molluscan Fossils from the Cretaceous Deposits of Hokkaidô and Japanese Saghalien. Part I. Lamellibranchiata and Scaphopoda," by Takumi Nagao. *Ibid.*, pp. 117–43; 3 plates of fossils.

KANSAS

"Late Paleozoic Pelecypods: Pectinacea," by Norman D. Newell. *State Geol. Survey Kansas*, Vol. 10 (1938). Quarto text, 123 pp., 20 full-tone pls. Price, $1.25. "This is a monographic treatment of one of the most important

groups of Paleozoic pelecypods with discussion of shell morphology, presentation of new classification of pectinoid pelecypods, and discussion of numerous genera and species, including many new forms."

KENTUCKY

The Saint Peter Sandstone in Kentucky, by Willard Rouse Jillson. The Standard Printing Company (1938), Louisville, Kentucky. Price, $1.00. "This is the first treatment of the Saint Peter formation in Kentucky. Its record and possibility as a deep oil and gas sand is indicated. Designed to be helpful as a guide for deeper drilling . . . " 46 pp., 1 map.

LOUISIANA

*"Natural Gas in Louisiana," by W. O. Chisholm. *Louisiana Conservation Review* (New Orleans, Spring issue, 1938), pp. 39–46; 7 photographs, 1 map. Reprinted from *Amer. Gas Jour.* (New York, May, 1938).

*"Big Things May Come from New Sparta-Wilcox Trend," by John D. Todd and Frank C. Roper. *Oil Weekly* (Houston), Vol. 90, No. 7 (July 25, 1938), pp. 78–86; 3 figs., 1 geological section.

MINNESOTA

*"Southern Minnesota Geology Studies for Oil Indications," by George A. Thiel. *Oil and Gas Jour.* (Tulsa), Vol. 37, No. 11 (July 22, 1938), pp. 57–58; 2 figs.

ROCKY MOUNTAIN REGION

*"Cambrian Formations and Sections in Part of Cordilleran Trough," by Charles Deiss. *Bull. Geol. Soc. America*, Vol. 49, No. 7 (July 1, 1938), pp. 1067–1168; 2 pls., 7 figs.

TEXAS

*"Heaving Shale Trends on Texas Gulf Coast," by J. M. Frost, III. *Oil Weekly* (Houston), Vol. 90, No. 7 (July 25, 1938), pp. 98–100; 1 fig., 1 table.

WYOMING

*"Geology of the Sheep Mountain Remnant of the Heart Mountain Thrust Sheet, Park County, Wyoming," by E. H. Stevens. *Bull. Geol. Soc. America*, Vol. 49, No. 8 (August 1, 1938), pp. 1233-66; 5 pls., 3 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 8, No. 2 (August, 1938).

"A Textural Study of the Outer Beach of Cape Cod, Massachusetts," by Marshall Schalk

"The Nature of Leucoxene," by S. A. Tyler and R. W. Marsden

"Petrology of Recent Sands of the Rhine and the Meuse in the Netherlands," by C. H. Edelman

"Stylolites in the Burlington Limestone near Kinderhook, Illinois," by John C. Frye and Ellis H. Scobey

"Floating Sand in the Formation of Swash Marks," by O. F. Evans

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 9 (SEPTEMBER, 1938), PP. 1292-1301

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Arnold D. Hoffman, Centralia, Ill.
Dorsey Hager, M. G. Hoffman, Ralph A. Brant
Leland L. Palmer, Wichita, Kan.
T. C. Hiestand, Kenneth A. Simmons, Edward A. Koester
Rudolph G. Sohlberg, Palo Alto, Calif.
George L. Knox, W. P. Winham, H. F. Davies
George Russell Sparenberg, Wichita Falls, Tex.
Howard S. Bryant, Edward A. Koester, W. G. Talbott
Murray J. Wells, Oklahoma City, Okla.
Clyde M. Becker, W. Melvin Stirtz, T. C. Hiestand

FOR ASSOCIATE MEMBERSHIP

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Arthur Wade, John M. Muir, W. D. Chawner
James Baldwin O'Flynn, Long Beach, Calif.
Frank A. Morgan, Manley L. Natland, John L. Porter
Bruce Harry Stinear, Christchurch, New Zealand
W. G. Argabrite, Harve Loomis, Charles F. Bowen
Walter Thomas Woodward, Taft, Calif.
W. F. Barbat, W. D. Kleinpell, Donuil Hillis

FOR TRANSFER TO ACTIVE MEMBERSHIP

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K. C. Heald, R. W. Clark, R. E. Somers
Samuel Warren Carey, Sydney, Australia
J. N. Montgomery, W. G. Woolnough, D. Dale Condit
Robert M. English, Mt. Vernon, Ind.
L. F. McCollum, O. A. Seager, Frank Gouin
Clenon C. Hemsell, Amarillo, Tex.
John E. Galley, T. C. Craig, J. V. Terrill
David T. Hoenshell, Avenal, Calif.
N. A. Rousselot, C. M. Wagner, Everett C. Edwards
Henry D. McCallum, Bastrop, Tex.
E. D. Pressler, W. A. Maley, L. F. McCollum
Lon B. Turk, Oklahoma City, Okla.
C. G. Carlson, A. I. Levorsen, J. T. Richards

SUPPLEMENTARY MEMBERSHIP LIST, SEPTEMBER 1, 1938

Members..... 81
Associates..... 149
Total additions since publication of list in March *Bulletin*... 230

Abernathy, G. E., State Geol. Survey of Kansas, Pittsburg, Kan.
Ackley, Kenneth A., Carter Oil Co., Seminole, Okla.
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Allison, Archibald, Anglo-Iranian Oil Co., Ltd., Masjid-i-suleiman, via Ahwaz, S. Iran
Anderson, James B., Barnsdall Oil Co., Los Angeles, Calif.
Anderson, Robert B., Forest Development Co., Abilene, Tex.
Archie, Gustave E., Shell Petr. Corp., Greenwich, Kan.
Arellano, A. R. V., Cia. Mex. de Petr. "El Aguila" S. A., Mexico, D. F.
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Augenthaler, Robert L., The California Co., 1500 Petroleum Bldg., Houston, Tex.

Babin, Logan H., 2617 Malcolm St., Shreveport, La.
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Beck, R. Stanley, Richfield Oil Corp., El Tejon Hotel Annex, Bakersfield, Calif.
Becker, Dwight L., Amerada Petr. Corp., Drawer 2040, Tulsa, Okla.
Becker, Herman Carroll, Geophysical Research Corp., Drawer 2040, Tulsa, Okla.
Behrmann, Rolf Bernhard, Deutsche Vacuum Oel A.G., Spitalerstr. 12/IV, Hamburg 1, Germany
Beltman, J. H., Keizerstraat 16, Deventer, Holland
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Bingham, D. H., Phillips Petr. Co., Levy Bldg., Lafayette, La.
Bingman, Neal J., Amerada Petr. Corp., Box 591, Midland, Tex.
Bishop, Margaret Stearns, Pure Oil Co., Houston, Tex.
Blair, Robert W., 551 Marion St., Denver, Colo.
Bocock, Oscar L., The Texas Co., Box 524, Corsicana, Tex.
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Boling, Kenneth G., Geol. Dept., Pure Oil Co., Box 311, Olney, Ill.
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Borger, Harvey D., Dept of Geology, University of Illinois, 232 Natural History Bldg., Urbana, Ill.
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Briggs, Colver R., Bureau of Power & Light, Box 240, Arcade Station, Los Angeles, Calif.
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Broussard, Lloyd J., Felmont Corp., 824 Esperson Bldg., Houston, Tex.
Browning, Iley B., consulting geologist, Box 126, Ashland, Ky.
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Bunsen, A. W., Adams Oil & Gas Co., 2303 Esperson Bldg., Houston, Tex.
Burke, James D., Salt Dome Oil Corp., 2600 Esperson Bldg., Houston, Tex.
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Reeves, James E., Dept. of Geology, Indiana Univ., Bloomington, Ind.
Roberts, Gerald C., Amerada Petr. Corp., Ardmore, Okla.
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Rose, Stanford L., The California Co., 810 U. S. Natl. Bldg., Denver, Colo.
Rowland, W. B., consulting geologist, 230 Gray St., Lake Charles, La.
Runyan, Felix A., Humble Oil & Refg. Co., 901 Humble Bldg., Houston, Tex.

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Senseman, R. B., Union Producing Co., Box 931, Beeville, Tex.
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Smith, J. Peter, Carter Oil Co., Room 7, Odd Fellows Bldg., Owensboro, Ky.
Smith, Ralph E., Texas Christian Univ., Fort Worth, Tex.
Spahr, Marshall Richard, Standard Oil Co. of Louisiana, Drawer 1739, Shreveport, La.
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Stringfield, V. T., U. S. Geol. Survey, Washington, D.C.

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Vesely, Leon R., Amerada Petr. Corp., 1811 Esperson Bldg., Houston, Tex.
Vernon, Benton R., Mid-Continent Petr. Corp., 323 Ardis Bldg., Shreveport, La.

Walton, George G., Magyar Amerikai Olajipari, Ferenc Jozsef Ter. 5, Budapest V, Hungary
Wilder, Newell M., Petroleum Exploration, Inc., Lexington, Ky.
Williams, Robert N., Jr., Honolulu Oil Corp., Bakersfield, Calif.
Williams, Thomas B., consulting geologist, 3406 Sixth St. West, Calgary, Alta., Canada
Wilson, Charles W., Jr., Vanderbilt Univ., Nashville, Tenn.
Wing, Robert B., Expl. Dept., Shell Petr. Corp., Tulsa, Okla.
Winkler, B. O., c/o N.K.P.M., Palembang, Sumatra, Netherlands Indies
Withers, F. Spencer, Atlantic Refg. Co., Box 169, Shawnee, Okla.
Woodward, Albert F., Mene Grande Oil Co., Apt. 35, Ciudad Bolivar, Venezuela, S.A.
Word, Charles F., Forest Development Corp., Box 1047, Abilene, Tex.

MID-YEAR MEETING, EL PASO, TEXAS, SEPTEMBER 27-OCTOBER 2, 1938

The program of field trips and technical papers of the mid-year meeting at El Paso has appeared in the August *Bulletin*, pages 1122–25.

The convention committee makes a last request about reservations. Because of limited hotel accommodations at points on the pre-convention field trips (*A*. Alamogordo-San Andres Mountains; *B*. Alpine-Glass Mountains), it is imperative that you return the numbered reservation card, or write immediately, indicating your preference of trips. Your reservations will be taken care of by the hotel arrangements committee *for field trips only*. Accordingly, communications concerning accommodations for these trips should be addressed to Georges Vorbe, chairman, Box 1147, Midland, Texas.

The publicity committee, James FitzGerald, Jr., chairman, presents the following information about round-trip railroad and airline rates to El Paso from key cities.

From	*Round Trip by Rail (Less Pullman)*	*Round Trip by Air*
Tulsa, Okla.	$37.85 Santa Fe	$ 92.40 American
Oklahoma City, Okla.	32.55 Santa Fe	84.30 American
Wichita, Kans.	34.80 Santa Fe	
Topeka, Kans.	39.65 Santa Fe	
Shreveport, La.	38.80 Texas & Pac.	78.90 American
Philadelphia, Pa.	94.65 Rock Island	202.74 American
Pittsburgh, Pa.	91.00 Rock Island	188.43 American
New Orleans, La.	52.55 Texas & Pac.	
St Louis, Mo.	55.00 Santa Fe	130.30 American
Chicago, Ill.	63.15 Santa Fe	155.30 American
Houston, Tex.	37.20 Southern Pac.	87.00 American
San Antonio, Tex.	27.75 Southern Pac.	88.80 American
Corpus Christi, Tex.	34.45 Southern Pac.	
Forth Worth, Tex.	27.70 Texas & Pac.	61.80 American
Dallas, Tex.	29.15 Texas & Pac.	61.80 American
Wichita Falls, Tex.	32.05 Texas & Pac.	
Amarillo, Tex.	20.05 Santa Fe	47.50 T.W.A.-Continental
Denver, Colo.	32.90 Santa Fe	53.00 Continental
Los Angeles, Calif.	36.80 Southern Pac.	88.35 T.W.A.-Continental
		70.50 American
Midland, Tex. (Airport, Big Spring)	13.90 Texas & Pac.	33.65 American
San Francisco, Calif.		104.60 American

In addition, there are many paved highways through El Paso; these roads within the state of Texas are all-weather highways and are used by many transcontinental tourists throughout the year.

A unique feature of the printed program of the mid-year meeting will be the correlation chart which has been composed by authors of papers and other interested geologists. This presents the nomenclature of the surface and subsurface formation of West Texas in an authoritative form to serve as a standard of reference; authors of papers will either use this nomenclature or point out their differences from it; auditors will be able to follow the argument without getting lost in a maze of unfamiliar names.

All geologists who differ from this chart are invited to construct their own correlation charts for exhibition on a bulletin board at the meeting. Advance copies of the official chart will be sent to any address on the receipt

Such scenes as this are common in the vicinity of El Paso, Texas, on the Mexican border. Giant yucca dot the desert, with beautiful silvery clouds floating overhead, making a paradise for photographers. Photograph by courtesy of the El Paso Chamber of Commerce and the El Paso County Board of Development, Gateway Club, El Paso, Texas.

of 25 cents per copy; these may be obtained from, and remittance therefor made to, Ronald K. DeFord, Box 865, Midland, Texas.

TWENTY-FOURTH ANNUAL MEETING, OKLAHOMA CITY MARCH 22–24, 1939

The twenty-fourth annual meeting of the Association will be held in Oklahoma City, Oklahoma, March 22, 23, and 24, 1939, at the invitation of the Oklahoma City Geological Society. E. A. Paschal, president of the Oklahoma City Society, announces the appointment of the following members to serve as the general committee in charge of the convention arrangements: J. T. Richards, Gulf Oil Corporation; R. W. Laughlin, of Laughlin-Simmons and Company; and John E. Van Dall, Magnolia Petroleum Company. Further announcements will be made in coming numbers of the *Bulletin*.

EIGHTEENTH INTERNATIONAL GEOLOGICAL CONGRESS LONDON, JULY 31-AUGUST 8, 1940

The 18th session of the International Geological Congress will be held in London from July 31 to August 8, 1940, according to the first circular (London, July, 1938) issued by the general organizing committee of which WILLIAM BRAGG, president of the Royal Society, is honorary president, and W. F. P. MCLINTOCK, deputy director of the Geological Survey of Great Britain, and W. B. R. KING, professor at University College, London, are general secretaries. The membership fee is £1 10s. The subjects for discussion are as follows.

1. Magmatic Differentiation
2. Metasomatic Processes in Metamorphism
3. Caledonids in North-west Europe
4. Rhythm in Sedimentation
5. The Geology of Iron-Ore Deposits
6. The Geology of Coal Seams
7. The Geology of Petroleum
8. The Geology of Sea and Ocean Floors
9. The Stratigraphical Limits of the Ordovician System
10. The Pliocene-Pleistocene Boundary
11. The Distribution of Early Vertebrates
12. Faunal Facies and Zonal Correlation
13. Earth Movements and Evolution
14. The Geological Results of Applied Geophysics

The following list of excursions is subject to change.

A. Before the Congress.—The following excursions have been provisionally selected to take place before the Congress, and will last from 7 to 14 days each (one 21 days).

A.1. The West Highlands and Islands of Scotland (most systems from pre-Cambrian onwards; Caledonian tectonics; Devonian and Tertiary igneous phenomena). 21 days approximately; by steamer or equivalent motor-coach transport.

A.2. The North of England, including the Lake District (mainly Lower Palaeozoic). 14 days approximately.

A.3. The Pennines (Carboniferous). 8 days approximately.

A.4. South Wales and the Bristol district (mainly Palaeozoic). 10 days approximately.

A.5. The Isle of Wight and Dorset (Mesozoic and Tertiary strata; tectonics). 12 days approximately.
A.6. Economic deposits (coal, ironstone, cement materials, slate, brick-earth, gypsum, etc.). 10 days approximately.
A.7. Cornwall and Devonshire (mineralogical). 7 days approximately.

It is also probable that an independent excursion to East Anglia will take place before the Congress, under the auspices and organization of the International Quaternary Union.

B. During and near the Congress.—It is hoped to arrange a series of short (half-day and day) excursions during the Congress to places of geological and general scientific interest in and around London, and also a series of short (2 to 3 days) excursions immediately prior to and after the session of the Congress. Details of these will be issued in a later circular.

C. After the Congress.—The following excursions (7 to 14 days each) have been provisionally selected.

C.1. A general excursion through England. 14 days approximately
C.2. The North-east of Ireland and Dublin district (pre-Cambrian to Tertiary), arranged in conjunction with representatives of Eire. 14 days approximately
C.3. The East Coast of the Scottish Highlands (metamorphic rocks, Caledonian intrusions, Old Red Sandstone). 8 days approximately
C.4. The Lowlands of Scotland (Ordovician to Carboniferous strata; volcanic and intrusive igneous rocks). 8 days approximately
C.5. The Midlands, Yorkshire, Cumberland, Lancashire, North Wales (glacial geology). 10 days approximately
C.6. North and Central Wales and the Welsh Border (mainly Lower Palaeozoic). 14 days approximately
C.7. South Wales and the Bristol district (Carboniferous). 7 days approximately
C.8. Devon and Cornwall (Hercynian Chain, granites, mineral veins). 10 days approximately
C.9. East Anglia (with emphasis on the Mesozoic and Pliocene rocks). 7 days approximately

Further information and later circulars will be issued by the General Secretaries, Eighteenth Session, International Geological Congress, Geological Survey and Museum, Exhibition Road, South Kensington, London, S. W. 7.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 9 (SEPTEMBER, 1938), PP. 1302-1304

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

It has been announced by the Geological Society of London that the International Geological Congress has accepted the Society's invitation to hold its XVIII Session in London in 1940. The Society will be aided by H. M. Geological Survey.

DON O. CHAPELL, Transwestern Oil Company, recently established Illinois offices for his company in the Klohr Building at Mattoon. Others connected with the office are L. S. HANDY, head of the land department, H. S. THOMAS, head of the paleontology department, and JACK DEARDORFF, scout.

GEORGE R. PINKLEY, South Texas representative for the Fohs Oil Company, is closing the company's office at San Antonio, and moving it to Corpus Christi. The change was effective, August 1.

CECIL G. LALICKER has resigned his position with the Phillips Petroleum Company at Corpus Christi to accept a position as assistant professor of geology at the University of Oklahoma at Norman.

G. S. HUME, Geological Survey of Canada, has spent the summer surveying the possibilities in the north Turner Valley field. Hume has recently completed a report on the southern section of the field.

W. A. BAKER, JR., chief geologist of the Standard Oil Company of New Jersey in Mexico, resigned on July 31, 1938. He can be addressed temporarily at P. O. Box 203, Brownsville, Texas.

R. C. LAFFERTY, president of the Appalachian Geological Society, recently discussed West Virginia gas deposits before a meeting of Charleston business men.

WILLIAM B. HEROY, a past-president of the Association, and for many years associated with the Consolidated Oil Corporation in New York, has joined the Pilgrim Exploration Company at Houston, Texas, as vice-president and chief geologist.

ERWIN H. BARBOUR, University of Nebraska, has retired after serving for nearly 47 years as professor of paleontology and director of the museum. A. L. LUGN, formerly associate professor, has been promoted to a full professorship, and C. BERTRAND SCHULTZ has been made assistant director in charge of the museum.

W. TAPPOLET has been transferred from the geological headquarters of the N. V. de Bataafsche Petroleum Maatschappij, The Hague, to Venezuela. His address is the Caribbean Petroleum Company, geological department, Maracaibo, Venezeula.

HORACE D. THOMAS, professor of geology at the University of Wyoming, has been employed for the summer season by the Oil and Gas Division of the Union Pacific Railroad.

The fall meeting of the Petroleum Division of the A.I.M.E. will be held at San Antonio, Texas, October 5–7. The Plaza Hotel is headquarters. The opening date, October 5, is one day earlier than originally announced in order to accomodate the extensive program.

Suit was filed on August 4, 1938, in the United States District Court for the Southern District of Texas, Houston Division, by the Schlumberger Well Surveying Corporation against the Halliburton Oil Well Cementing Company. The Schlumberger Well Surveying Corporation is charging infringement of certain of its United States patents. The complaint asks for an injunction, for an accounting for profits, and for damages.

LESTER L. WHITING, The Texas Company, has been transferred to Oklahoma City to act as district geologist. He was formerly in the Wichita, Kansas, office.

HORACE L. SCOTT has resigned as geologist for Manning and Martin, Inc., Denver, Colorado, to attend to personal business. He may be addressed at Huntsville, Arkansas.

F. W. ROHWER, formerly located at La Brea, Trinidad, may now be addressed at 1433 Pine Street, Boulder, Colorado.

FRED C. SEALEY, The Texas Company, has been transferred from Los Angeles to New York as manager of foreign producing operations.

H. M. KIRK, Inland Exploration Company, formerly stationed at Kabul, Afghanistan, may now be addressed at 39 Broadway, New York.

ANDREW MILEK, has changed his address from Apartado 241, Tampico, Tamps., Mexico, to Room 2763, 630 Fifth Avenue, New York.

PARKE A. DICKEY, formerly with the Tropical Oil Company at Barrancabermeja, Colombia, South America, is now employed as oil and gas geologist with the Pennsylvania Topographic and Geologic Survey, with headquarters at Harrisburg, Pennsylvania.

CLEMENTE LEIDHOLD has been transferred from the Comodoro Rivadavia field to Buenos Aires, and may be addressed as follows: Depto. de Exploración, Yacimientos Petrolíferos Fiscales, Av. R. S. Peña 777, Buenos Aires, Argentina, S. A.

President DONALD C. BARTON has been busy with affairs of the Association this summer. In June he visited headquarters at Tulsa, in conference with secretary-treasurer IRA H. CRAM. In July he met with past-president H. B. FUQUA and secretary-treasurer Cram in executive committee session at Oklahoma City. On August 1, he met with the general committee of the West Texas Geological Society, at Midland, planning for the mid-year meeting at El Paso, Texas, September 27–October 2. On August 8, he met with

the Western Kentucky Geological Society at Owensboro; on August 10, with the Appalachian Geological Society at Charleston, West Virginia; later in the month, with members of the Association in New York and New England; on August 26, with the Michigan Geological Society at Mount Pleasant; August 29, with southern Illinois geologists at Mattoon; and on August 31-September 2, on the field trip of the Kansas Geological Society and the Rocky Mountain Association of Petroleum Geologists.

BEN L. PILCHER, JR., formerly district geologist for The Texas Company at Amarillo, Texas, has been transferred to Fort Worth, Texas, to fill the position of assistant division geologist. H. G. WALTER, formerly at Hobbs, New Mexico, succeeds Pilcher in the Amarillo office.

B. S. RIDGEWAY, formerly at Mount Pleasant, Michigan, is in charge of the new production office of the Cities Service Oil Company at Mattoon, Illinois. He is assisted by J. L. FOSNESS.

JOHN H. REEVE, United States Geological Survey, has been appointed oil and gas supervisor for the Mid-Continent district. He was formerly district supervisor at Casper, Wyoming. FOSTER MORRELL, who has been acting supervisor for the Mid-Continent district since the death of John M. Alden, is remaining in the Tulsa office as deputy supervisor.

THOMAS L. COLEMAN, district engineer in the oil and gas leasing division of the United States Geological Survey, has been transferred to Ardmore, Oklahoma, from Wichita Falls, Texas.

KENNETH L. GOW, Superior Oil Company, recently spoke before the Rotary Club at Mattoon, Illinois, on the subject "Geological Exploration in Oil."

R. B. NEWCOMBE, head of the geological and lands division of the Associated Petroleum Company of Detroit, resigned on September 1, to become an independent consulting geologist.

MORTON T. HIGGS, the Lane-Wells Company, has been made division sales manager of the Gulf Coast division.

The South Texas Section of the Association will hold its annual meeting at Corpus Christi, Texas, October 21 and 22. W. A. MALEY, of the Humble Oil and Refining Company, Corpus Christi, is president, and C. C. MILLER, of The Texas Company, Corpus Christi, is secretary-treasurer. The technical program will feature the geologic section of the late Eocene and the Miocene.

The Pacific Section of the Association, W. S. W. KEW, Standard Oil Company of California, president, and E. WAYNE GALLIHER, Barnsdall Oil Company, secretary-treasurer, both of Los Angeles, will hold its annual meeting at Los Angeles, November 3 and 4.

S. GRACE HOWER, who was engaged in special geological graduate work and in teaching at Bryn Mawr College during 1936 and 1937, is now in the employ of the Aero Exploration Company at Tulsa.

The total number of members in the Association on September 1, 1938, was 2,877, of which 2,202 were active or full members and 175 were associate members. This is a new high record.

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GENERAL OFFICE, *Revue de Géologie,* Institut de Géologie, Université de Liége, Belgium.

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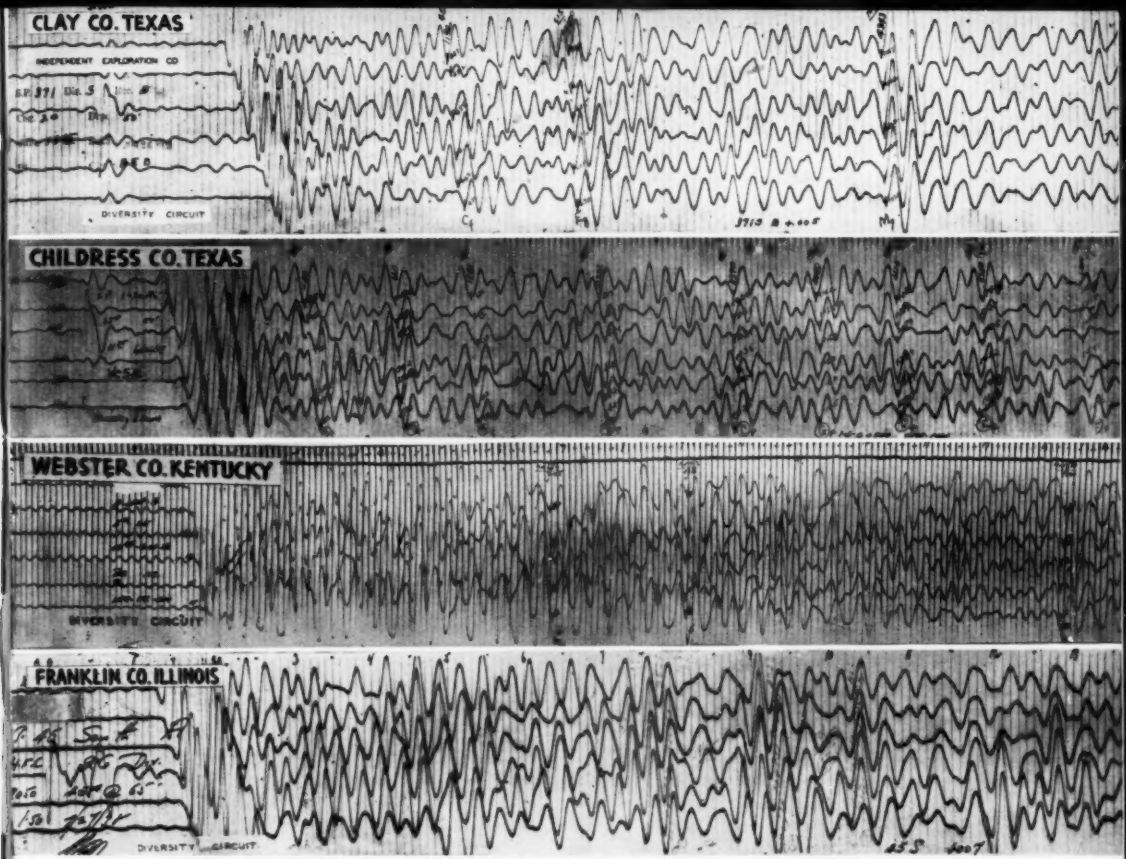

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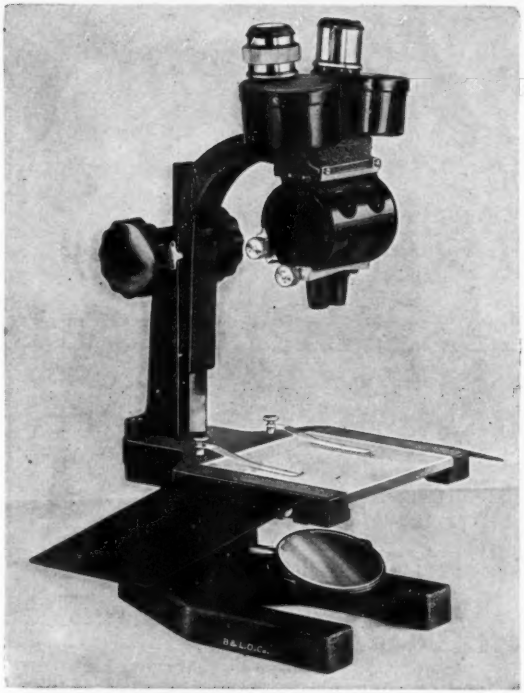

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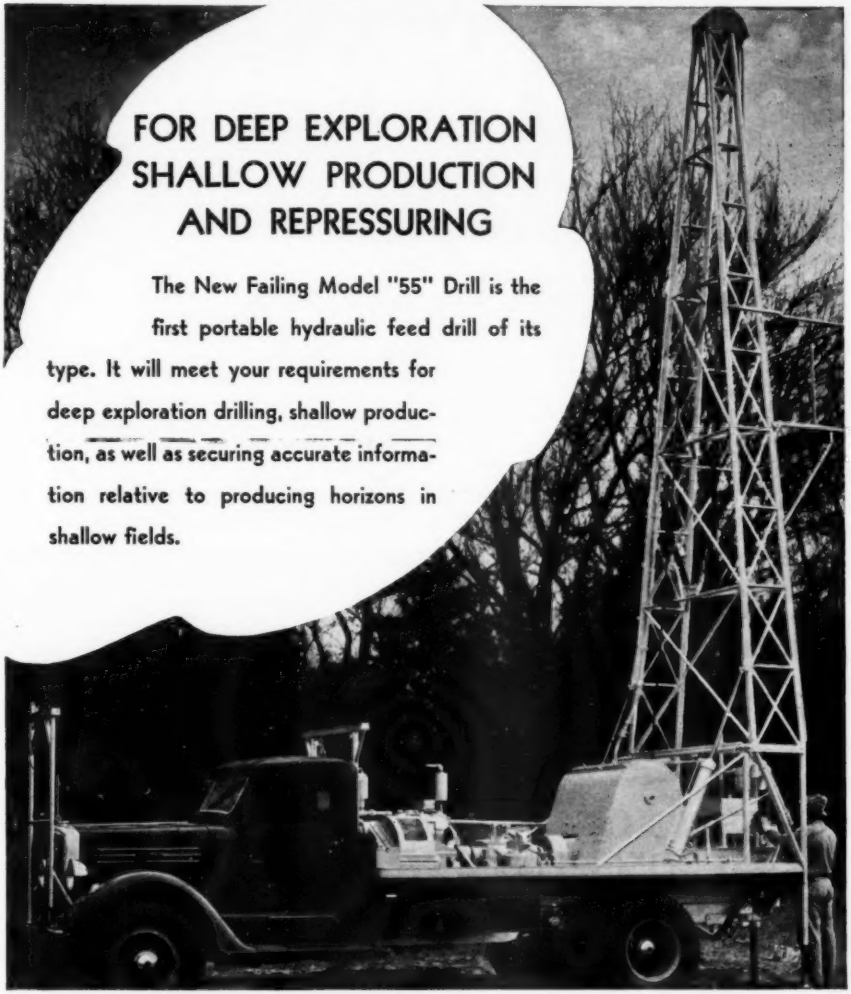

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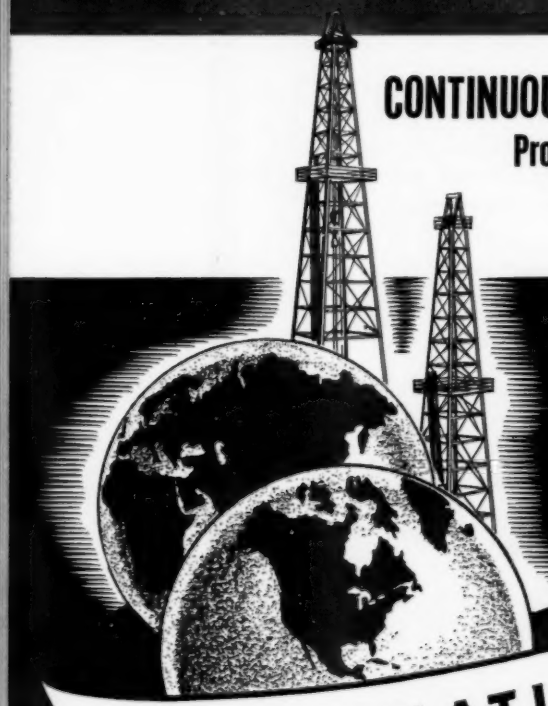

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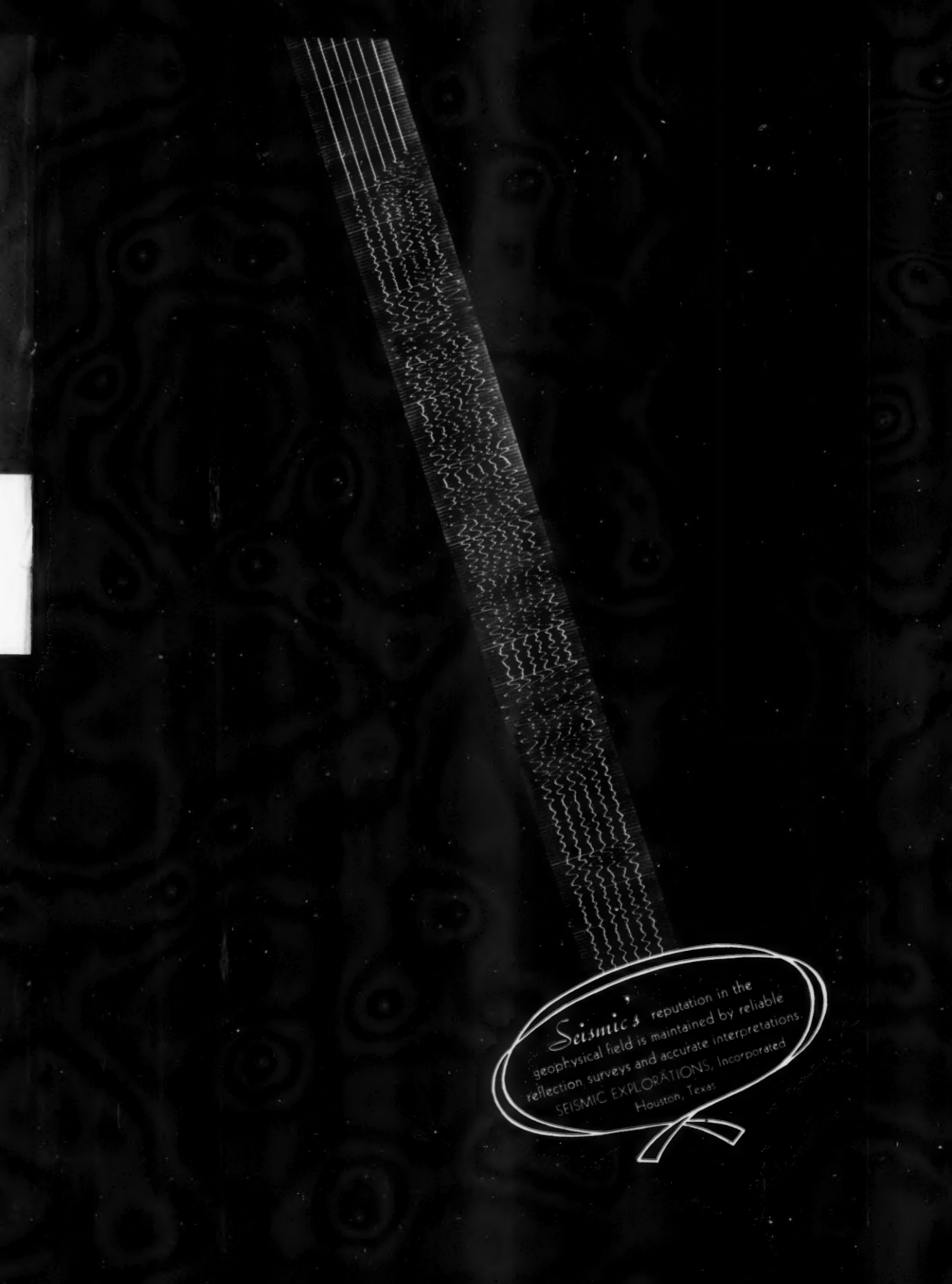
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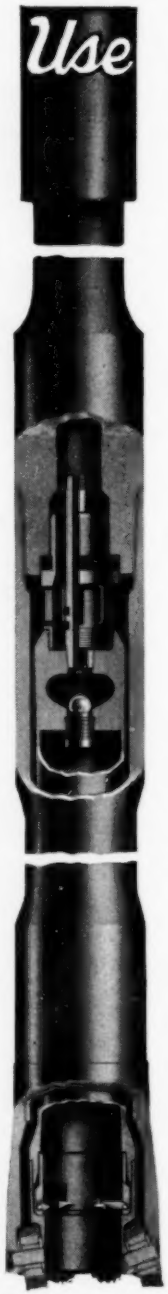

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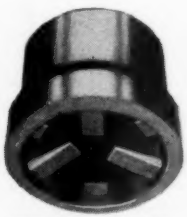

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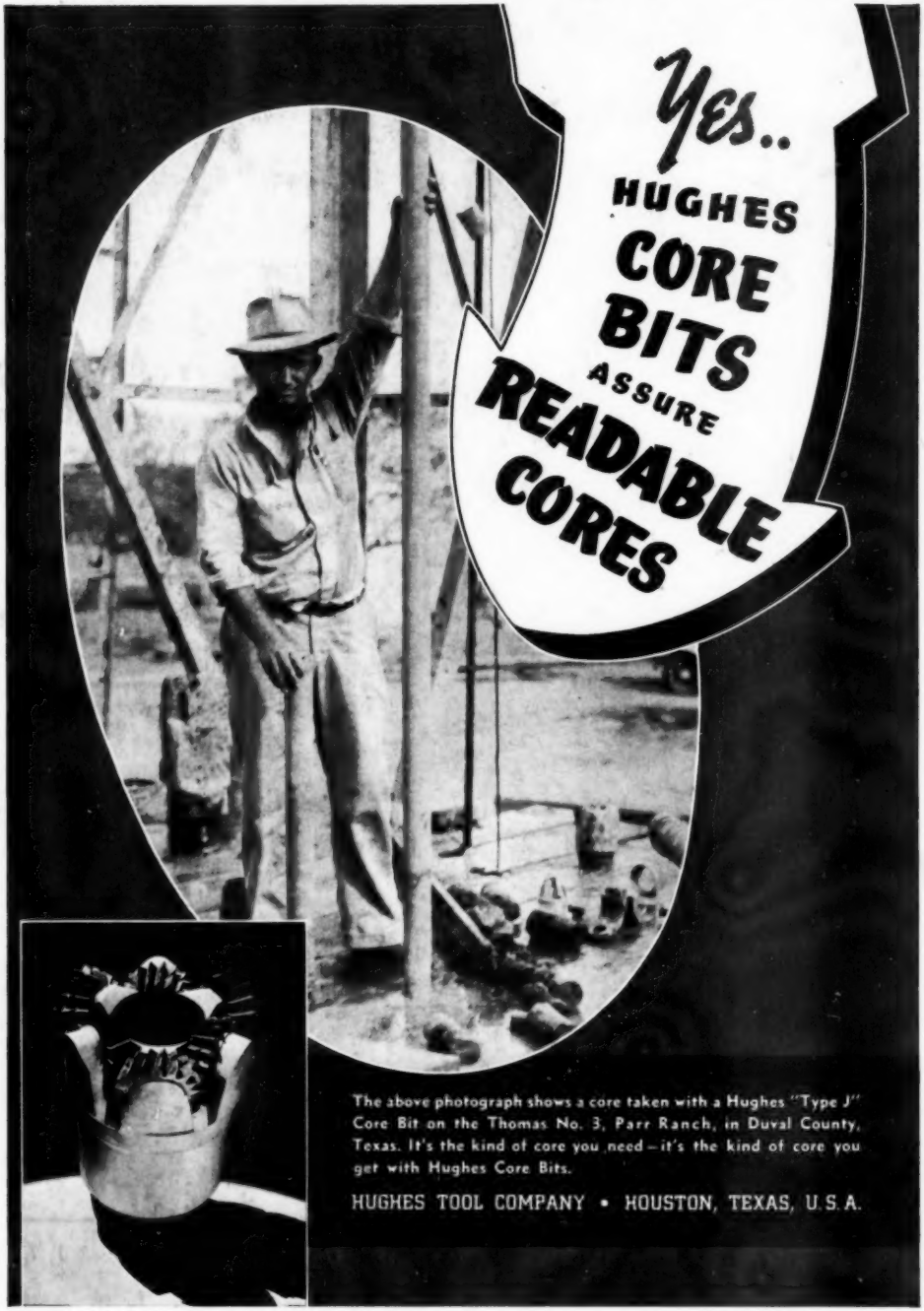
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